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VISUAL PATTERN-DISCRIMINATION IN THE VERTEBRATES—III

EFFECTIVE DIFFERENCES IN WIDTH OF VISIBLE STRIAE FOR THE MONKEY AND THE CHICK

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In an experiment reported some time ago[1] I determined the width of the individual members of a regular system of striae necessary to enable three animals to distinguish the field as striate at a given distance and under the experimental conditions prescribed. The work reported in this paper was done on the same animals, in an attempt to ascertain what difference in width of the members of two regular systems of striae, both of which the animals can distinguish as such, is necessary to effect discrimination between the two systems. The discriminands are two interchangeable circular fields, 6 cm. in diameter and equal in brightness and color. The distribution of energy through the visible spectrum approximated that of a tungsten lamp operated at a specific consumption of 1.25 watts per candle. In the work on the chickens the mean brightness of the fields was 12.24 candles per square meter; in the work on the monkey, 6.67 candles per square meter; and in a supplementary test made on two human subjects, 6.24 candles per square meter. The striae composing the system on the positive field are coarser and fewer in number than those composing the system on the negative field. The animals were fed in the food-compartment

[1] Johnson, H. M. Visual pattern-discrimination in the vertebrates. II. Comparative visual acuity in the dog, the monkey and the chick. This journal, vol 4, 1914, pp. 340-361.

indicated by the positive field, and were punished by an electric shock for attempting to enter the food-compartment indicated by the negative field. In an earlier communication[2] I described at some length the optical instruments used, and the methods of preparing the stimuli and of training the animals.[3] I followed these methods rigidly in the present work except in three particulars. It became necessary, when the differences in width between the members of the two systems of striae became small, to make the adjustments by hand, employing the micrometer screw for the purpose, instead of using the string and pulley mechanism. Further, in this work it is unnecessary that each animal be required to compare the test-fields at the same minimal distance as that prescribed for another animal, in order to make the results comparative. I therefore eliminated the stops in front of the alleys A^1 and A^2 of the Yerkes box (shown in figure 6 of the last article cited) which I had used in the work on the chicks. This reduced to 50 cm. the minimal distance at which comparison could be made without a choice being registered. The actual distance usually employed by the birds seemed to be between 50 cm. and 60 cm. If the difference in width of the members of the two systems was large as compared with the least effective difference for the individual, the animals tended to choose without comparing except possibly from the position they happened to occupy in the home-compartment when the exit-door was raised and the test-fields exposed. I retained the plate glass partition formerly used in the work on the monkey, in order to limit his movements. In this work he occasionally thrust his head into one opening in this partition and withdrew it without choosing that alley. Such behavior was relatively infrequent, and in such cases I did not exclude the responses. In practically all the presentations in which he compared the two fields before choosing, he inspected them successively with

[2] Johnson, H. M. Visual pattern-discrimination in the vertebrates. I. Problems and methods. This journal, vol. 4, 1914, pp. 319-339.

[3] The original drawing for Figure 1 in that article was lost or destroyed after it had been mailed to the printer. A second drawing had to be prepared hastily and was used. It contains an error which I beg the reader, in the interest of clearness, to correct. The acute angle I, II, in the figure should be lettered φ, and the obtuse angle I, II, should be lettered φ^1 instead of φ. The system of right lines bisecting the obtuse angle should be lettered III. On page 330, in the phrase, "the lines III bisect the angle I, II (φ)," the symbol φ^1 should be substituted for the symbol φ. My responsibility for the error is limited to carelessness in copy and proofreading.

his eyes in or quite near the plane of the windows in the partition—60 cm. from the test-field. In all cases I recorded as the alley "chosen" the one into which the animal first stepped. The animals automatically and instantly registered their choices by breaking the circuit through a signal lamp as they stepped on to the floor of the alley. The third change is the introduction of a shallow copper tray into the Yerkes box, between the exit-door and the alleys A^1 and A^2. This tray contained a moistened felt pad[4] on to which the animal had to step before he could enter the alley. This tended to minimize the variability of the resistance of the animal's feet. It is somewhat more satisfactory than the means employed in my earlier work—that of soaking the animal's feet before beginning the daily series of trials.

RELATIVE EASE OF LEARNING FOR INDIVIDUAL ANIMALS

The animals used were a young male Capuchin monkey and two Indian gamecocks. They were described in paper No. 2 of this series, and designated severally as Monkey 2 and Chicks 1 and 2. Since that report was published, Dr. P. W. Cobb refracted the eyes of the birds by skiascopy. The static error

[4] Breed had used a similar device in his work on the chick. Some such precaution is indispensable to good results if punishment with electric shock is employed. The resistances of dry feet and moist feet are of different orders of magnitude. If an animal is put into the box with dry feet and hands, and if during the series the latter become moist, as from perspiration or contact with urine or wet food, the increased effect of a steady line current may work great disturbance. In my work on audition in dogs I found this factor troublesome. Miss E. M. Smith reports a similar experience. The unsatisfactory results reported by some other experimenters may be partly due to failure to take this precaution. Watson (Behavior, p. 60) asserts that some animals " are extremely resistant even to fairly high currents. The rabbit is not disturbed in the smallest degree by a current which is unbearable to the human being." It should be remembered that thick tufts of long hair cover the soles of the rabbit's feet, forming an excellent insulation when dry. When moistened, the water acts as a conductor. The rabbit will then react violently to a current which is not unpleasantly strong when received by the human subject through the moistened finger-tips. I recently demonstrated this fact in a simple experiment on the rabbit. However, even with the best attempts to keep the resistance of the animal's feet constant, the variability is fairly large—as great, I have been told, as 25%. It is impossible to keep the animal's feet free of dirt and grease, which interfere with good contact with the electrodes. It therefore seems unnecessary to use such extreme care to control the steadiness of the line current as some students have done. I have obtained satisfactory results by passing A.C. from the city circuit through the primary coil of a Zimmermann inductorium, connecting a bank of lamps in series with the coil and in parallel with each other. Small changes in intensity of shock can be made by changing the position of the secondary coil with reference to the primary. This method has one advantage over the use of D.C. with an interrupter, in that the noise of the latter, which is often a source of disturbance, is dispensed with.

under mydriasis for Chick 1 was 0.75 D. hyperopia in the right eye and 1.25 D. hyperopia in the left eye. For Chick 2 the error was between 0.25 D. and 0.50 D. hyperopia in both eyes. No astigmatism was discoverable in either bird. After the animals had recovered from mydriasis, Dr. Cobb repeated the tests, but, since the birds were continually changing their accommodation, the results were quite indefinite. In the emmetropic human eye an hyperopia as great as that found for Chick 2 usually exists during mydriasis, owing to lack of tone in the ciliary muscle. It seems fair, therefore, to regard this bird's eyes as practically emmetropic, since no error was discoverable without mydriasis.

Chick 1 failed to establish a perfect or highly accurate habit in 300 trials, although the width of the members of the positive system of striae was three times as great as that of the members of the negative system. At this point I abandoned the attempt to train him. Later on I gave him the problem of discriminating between two regular systems of striae the members of which were equal in width, but differed in direction by 90°. He failed to learn this problem also. When I introduced a 2 to 1 difference in width in addition to the difference in direction, he established a perfect habit in 150 additional trials, and maintained discrimination until the relative width of the members of the two systems was reduced to a 5 to 4 relation. The bird's record over 1100 trials indicated that a difference in either width or direction is ineffective if it is presented alone, but that either difference is effective if it is made sufficiently large and is presented with a maximal difference in the other characteristic. This fact raised some questions of great interest, which I was prevented from studying by an injury to the bird's left eye. I shall, therefore, omit a detailed report on the work done on Chick 1.

Chick 2 and Monkey 2 learned the problem in less than 100 trials each.

BASIS OF DISCRIMINATION

In attempting to train an animal to respond to a difference between two stimuli either of which may be made the variable, it is important to know whether the animal is reacting on the basis of relative difference, or by choosing or rejecting a familiar stimulus. If in work on this problem, the animal can be trained

invariably to compare the test-fields and choose the coarser system regardless of the absolute width of its members, it would seem feasible to adopt the method of right and wrong cases, presenting in haphazard order large and small differences in both directions from the standard, and to treat the results statistically. The advantages of using such a method in preference to the cruder methods on which we have thus far had to rely are obvious.

TABLE 1

DAILY RECORD OF CHICK 2

Date 1914	Width (mm.) of striae on Positive field	Negative field	Number of Trials given	Correct responses	Remarks
Feb. 13	2.23	0.92	10	8	Not worked on days for which no record is given
" 14	2.23	0.92	10	10	
" 15	2.23	0.92	10	9	
" 16	2.23	0.92	10	9	
" 17	2.23	0.98	10	8	
" 18	2.23	0.98	10	8	
" 19	2.23	0.98	10	9	
" 20	2.23	0.98	10	8	
" 21	2.23	0.98	10	8	
" 22	2.23	0.98	10	9	
" 23	2.23	0.98	10	9	
" 24	2.23	0.98	10	10	
" 25	2.23	0.98	10	10	
" 26	2.23	0.98	10	10	
" 27	2.23	1.00	10	10	
" 28	2.23	1.02	10	8	Disturbed by punishment
Mar. 1	2.23	1.02	10	10	
" 2	2.23	1.08	10	8	
" 3	2.23	1.08	10	10	
" 3	2.23	1.11	10	9	
" 4	2.23	1.11	10	9	
" 5	2.23	1.11	20	15	Greatly excited by punishment
" 9	2.23	0.11	10	10	
" 11	2.23	0.11	10	10	Responses very slow
" 12	2.23	0.11	10	10	Responses very slow
" 13	2.23	0.11	10	10	More active
" 14	2.23	0.11	10	10	Active
" 15	2.23	0.11	10	10	Active
" 16	2.23	0.11	5	5	
" 16	2.23	1.04	5	5	
" 16	2.23	1.11	10	10	
" 17	2.23	1.08	5	4	
" 17	2.23	1.11	5	5	
" 17	2.23	1.15	10	10	
" 18	2.23	1.11	5	5	
" 18	2.23	1.15	5	5	
" 18	2.23	1.18	20	18	
" 19	2.23	1.15	5	5	
" 19	2.23	1.18	5	4	

TABLE 1—*Continued*

Date 1914	Width (mm.) of striae on: Positive field	Negative field	Number of: Trials given	Correct responses	Remarks
Mar. 19	2.23	1.22	20	16	
" 20	2.23	1.15	5	4	
" 20	2.23	1.22	5	5	
" 20	2.23	1.28	20	11	Taken as threshold
" 20	2.23	0.92	10	10	Given as test of bird's condition
" 21	2.23	1.11	10	10	
" 21	4.33	2.23	10	3	Chose familiar field against punishment
" 22	4.33	2.23	10	4	
" 23	2.23	1.11	10	8	
" 23	4.33	2.23	10	4	Chose familiar field against punishment
" 24	4.33	2.23	10	2	
" 25	2.23	0.92	10	9	
" 25	1.95	0.92	10	10	
" 25	1.73	0.92	10	8	
" 26	1.95	0.92	5	5	
" 26	1.73	0.92	5	5	
" 26	1.56	0.92	5	5	
" 26	1.42	0.92	10	7	
" 27	1.56	0.92	10	9	
" 27	1.42	0.92	5	5	
" 27	1.30	0.92	10	7	
" 28	1.42	0.92	5	5	
" 28	1.30	0.92	10	5	Taken as threshold
Apr. 5	2.60	0.98	10	9	
" 6	2.60	1.04	10	9	
" 7	2.60	1.04	10	8	
" 7	2.60	1.11	10	9	
" 8	2.60	1.11	5	5	
" 8	2.60	1.20	5	5	
" 8	2.60	1.30	10	9	
" 9	2.60	1.39	5	4	
" 9	2.60	1.44	5	4	
" 9	2.60	1.53	10	10	
" 9	2.60	1.73	10	6	Taken as threshold
" 15	3.12	1.04	10	10	
" 16	3.12	1.04	10	10	
" 17	3.12	1.04	10	10	
" 18	3.12	1.11	5	5	
" 18	3.12	1.20	5	5	
" 18	3.12	1.30	5	5	
" 18	3.12	1.42	5	4	
" 19	3.12	1.42	10	10	
" 20	3.12	1.42	5	5	
" 20	3.12	1.56	10	8	
" 21	3.12	1.56	10	8	
" 30	3.12	1.56	20	15	
May 1	3.12	1.56	10	8	
" 2	3.12	1.56	10	8	
" 3	3.12	1.56	10	9	
" 3	3.12	1.73	10	8	
" 4	3.12	1.30	5	5	
" 4	3.12	1.81	10	7	Taken as threshold
" 5	3.12	1.30	5	5	

TABLE 1—*Continued*

Date 1914	Width (mm.) of striae on: Positive field	Negative field	Number of: Trials given	Correct responses	Remarks
May 5	3.12	1.90	10	6	
" 5	3.12	1.04	5	5	
" 5	2.60	1.04	5	5	
" 6	2.23	1.04	5	5	
" 6	1.95	1.04	10	6	Greatly excited by punishment
" 7	2.23	1.04	10	8	Still excitable
" 11	2.23	1.04	10	9	
" 12	2.23	1.04	10	10	
" 12	1.95	1.04	10	10	
" 12	1.73	1.04	10	8	
" 13	1.73	1.04	5	5	
" 13	1.56	1.04	10	8	
" 13	1.44	1.04	10	6	Taken as threshold
" 13	3.12	1.04	5	5	Taken as test of bird's condition
" 14	1.30	0.74	10	10	
" 14	1.20	0.74	20	16	
" 14	1.11	0.74	10	8	
" 15	1.30	0.74	10	10	
" 15	1.04	0.74	10	6	Taken as threshold

TABLE 2

DAILY RECORD OF MONKEY 2

Date 1914	Width (mm.) of striae on: Positive field	Negative field	Number of: Trials given	Correct responses	Remarks
June 7	1.561	0.780	10	6	Very inactive
" 8	1.561	0.780	10	4	
" 9	1.561	0.780	10	7	
" 10	1.561	0.780	10	7	
" 11	1.561	0.780	10	8	Compared in 9 trials
" 12	1.561	0.780	10	9	
" 13	1.561	0.780	10	10	
" 14	1.561	0.780	10	10	
" 16	1.561	0.780	10	10	Not worked on days for which no record is given
" 17	1.561	0.822	10	10	
" 18	1.561	0.867	10	10	
" 19	1.561	0.908	10	10	
" 20	1.561	0.976	10	10	
" 21	1.561	1.041	10	10	
" 22	1.561	1.115	10	10	
" 23	1.561	1.201	10	10	
" 24	1.561	1.301	10	10	
" 27	1.561	1.301	10	9	
" 28	1.561	1.301	10	4	
" 29	1.561	1.301	10	7	
" 30	1.561	1.301	10	7	
July 1	1.561	1.301	10	5	
" 1	1.561	0.976	5	5	
" 2	1.561	0.976	5	5	
" 2	1.561	1.115	5	5	

TABLE 2—*Continued*

Date 1914	Width (mm.) of striae on: Positive field	Negative field	Number of: Trials given	Correct responses	Remarks
July 2	1.561	1.301	10	8	Taken as threshold
" 3	2.602	1.561	10	6	
" 4	2.602	1.561	10	7	
" 5	2.602	1.561	10	8	
" 6	2.602	1.561	10	10	
" 7	2.602	1.561	10	10	
" 8	2.602	1.561	10	10	
" 9	2.602	1.561	10	10	
" 10	2.439	1.561	10	10	
" 11	2.439	1.561	10	10	
" 12	2.296	1.561	10	10	
" 13	2.296	1.561	10	10	
" 13	2.168	1.561	10	10	
" 14	2.168	1.561	10	9	
" 14	2.001	1.561	10	10	
" 15	1.904	1.561	10	9	
" 16	1.904	1.561	20	19	
" 17	1.904	1.561	10	9	
" 17	1.815	1.561	10	10	
" 18	1.815	1.561	10	10	
" 18	1.734	1.561	10	6	
" 19	1.815	1.561	10	9	
" 20	1.815	1.561	10	9	
" 21	1.774	1.561	10	7	
" 24	1.774	1.561	10	7	Taken as threshold
Aug. 10	0.780	0.446	10	6	In bad condition since July [24
" 11	0.780	0.446	10	4	Refused food
" 12	0.780	0.446	10	9	
" 13	0.780	0.446	10	7	
" 14	0.780	0.446	10	10	
" 15	0.780	0.446	10	10	
" 16	0.780	0.446	10	10	
" 17	0.780	0.520	10	9	
" 18	0.780	0.520	10	9	
" 19	0.780	0.538	10	10	
" 20	0.780	0.558	10	10	
" 21	0.780	0.578	10	8	
" 22	0.780	0.520	3	3	
" 22	0.780	0.578	2	2	
" 22	0.780	0.600	10	10	
" 23	0.780	0.520	2	2	
" 23	0.780	0.558	3	3	
" 23	0.780	0.624	10	10	
" 24	0.780	0.520	2	2	
" 24	0.780	0.558	3	3	
" 24	0.780	0.650	10	10	
" 25	0.780	0.520	2	2	
" 25	0.780	0.558	3	3	
" 25	0.780	0.679	12	7	
" 26	0.780	0.520	1	1	
" 26	0.780	0.558	2	1	
" 26	0.780	0.600	5	5	
" 26	0.780	0.650	3	3	
" 26	0.780	0.655	10	8	

TABLE 2—*Continued*

Date 1914	Width (mm.) of striae on Positive field	Negative field	Number of Trials given	Correct responses	Remarks
Aug. 27	0.780	0.600	10	9	
" 27	0.780	0.661	10	9	
" 28	0.780	0.600	10	9	
" 28	0.780	0.667	10	10	
" 29	0.780	0.600	10	10	
" 29	0.780	0.673	10	5	Taken as threshold
" 30	1.040	0.780	10	10	
" 31	0.918	0.780	10	10	
Sept. 1	0.918	0.780	10	10	
" 1	0.909	0.780	10	9	
" 2	0.918	0.780	10	10	
" 2	0.897	0.780	10	10	
" 3	0.918	0.780	10	9	
" 3	0.890	0.780	10	7	Taken as threshold
" 4	0.650	0.520	10	10	
" 5	0.624	0.520	10	10	
" 6	0.624	0.520	10	10	
" 6	0.615	0.520	10	8	
" 7	0.624	0.520	10	8	
" 7	0.610	0.520	10	7	Taken as threshold
" 8	0.624	0.520	10	9	
" 8	0.605	0.520	10	7	
" 9	0.520	0.390	10	9	
" 10	0.520	0.400	10	9	
" 11	0.520	0.411	10	10	
" 13	0.520	0.422	10	9	
" 13	0.520	0.434	10	10	
" 15	0.520	0.446	10	9	
" 15	0.520	0.459	10	7	
" 16	0.520	0.446	10	8	
" 16	0.520	0.467	10	8	
" 17	0.520	0.434	10	8	
" 17	0.520	0.473	10	9	
" 18	0.520	0.434	10	10	
" 18	0.520	0.479	10	7	Taken as threshold
" 19	0.520	0.434	10	10	
" 19	0.520	0.488	10	6	
" 20	0.459	0.390	20	17	
" 21	0.459	0.390	10	10	
" 21	0.446	0.390	10	8	
" 22	0.459	0.390	10	10	
" 22	0.441	0.390	10	8	
" 23	0.459	0.390	10	10	
" 23	0.436	0.390	10	9	
" 25	0.459	0.390	9	9	
" 25	0.431	0.390	11	10	
" 27	0.459	0.390	10	10	
" 27	0.427	0.390	10	7	
" 28	0.459	0.390	10	10	
" 28	0.422	0.390	10	10	
" 29	0.459	0.390	10	10	
" 29	0.417	0.390	10	9	
" 30	0.459	0.390	10	10	
" 30	0.413	0.390	12	8	Taken as threshold

TABLE 2—*Continued*

Date 1914	Width (mm.) of striae on: Positive field	Negative field	Number of: Trials given	Correct responses	Remarks
Oct. 1	0.459	0.390	10	9	
" 1	0.409	0.390	10	7	
" 2	0.390	0.325	10	10	
" 2	0.390	0.339	10	7	
" 3	0.390	0.339	10	9	
" 4	0.390	0.339	10	10	
" 5	0.390	0.339	10	10	
" 5	0.390	0.347	10	9	
" 6	0.390	0.339	10	10	
" 6	0.390	0.355	10	8	
" 7	0.390	0.339	10	8	
" 7	0.390	0.358	10	10	
" 8	0.390	0.339	10	10	
" 8	0.390	0.361	10	7	
" 9	0.390	0.339	10	10	
" 9	0.390	0.365	10	9	
" 10	0.390	0.339	10	10	
" 10	0.390	0.368	10	10	
" 11	0.390	0.339	10	9	
" 11	0.390	0.371	10	7	
" 12	0.390	0.339	10	9	
" 12	0.390	0.371	10	7	Taken as threshold
" 13	0.347	0.312	20	19	
" 17	0.347	0.312	20	15	Distracted by noise outside
" 19	0.372	0.312	10	8	
" 19	0.347	0.312	10	7	
Nov. 11	0.390	0.312	20	17	
" 12	0.390	0.312	20	15	
" 13	0.390	0.312	20	15	
" 14	0.390	0.312	15	12	
" 15	0.390	0.312	15	15	
" 16	0.434	0.312	20	16	
" 17	0.422	0.312	20	20	
" 18	0.411	0.312	10	10	
" 18	0.400	0.312	10	9	
" 19	0.390	0.312	20	17	
" 20	0.381	0.312	20	20	
" 21	0.372	0.312	10	10	
" 21	0.363	0.312	10	10	
" 22	0.354	0.312	10	10	
" 22	0.346	0.312	10	9	
" 23	0.346	0.312	10	10	
" 23	0.339	0.312	10	8	
" 24	0.346	0.312	10	8	
" 24	0.335	0.312	10	9	
" 25	0.346	0.312	10	9	
" 25	0.332	0.312	10	9	
" 26	0.346	0.312	10	9	
" 26	0.328	0.312	10	9	
" 27	0.346	0.312	10	10	
" 27	0.325	0.312	10	10	
" 28	0.346	0.312	10	8	
" 28	0.321	0.312	10	8	
" 29	0.346	0.312	10	9	

TABLE 2—*Continued*

Date 1914	Width (mm.) of striae on Positive field	Negative field	Number of Trials given	Correct responses	Remarks
Nov. 29	0.321	0.312	10	5	Taken as threshold
" 30	0.312	0.260	20	16	
Dec. 1	0.312	0.260	10	10	
" 1	0.312	0.264	10	10	
" 2	0.312	0.269	10	10	
" 2	0.312	0.274	10	10	
" 3	0.312	0.279	10	10	
" 3	0.312	0.284	10	10	
" 4	0.312	0.289	10	9	
" 4	0.312	0.294	10	9	
" 5	0.312	0.284	10	9	
" 5	0.312	0.298	10	9	
" 6	0.312	0.284	10	10	
" 6	0.312	0.300	10	8	
" 7	0.312	0.284	10	9	
" 7	0.312	0.304	10	8	Taken as threshold
" 8	0.312	0.284	10	10	
" 8	0.312	0.306	10	5	
" 8	0.312	0.284	10	8	Control test to determine basis of choice
" 8	0.284	0.260	10	10	
" 9	0.244	0.223	10	9	
" 9	0.240	0.223	10	10	
" 9	0.236	0.223	10	9	
" 10	0.244	0.223	6	6	
" 10	0.234	0.223	10	8	
" 10	0.232	0.223	15	11	
" 11	0.244	0.223	10	9	
" 11	0.232	0.223	10	7	Taken as threshold
" 11	0.223	0.199	10	9	
" 12	0.223	0.199	10	9	
" 13	0.223	0.199	10	9	
" 13	0.223	0.200	10	10	
" 14	0.223	0.200	10	10	
" 14	0.223	0.203	10	10	
" 15	0.223	0.203	10	10	
" 15	0.223	0.208	10	9	
" 16	0.223	0.203	10	9	
" 16	0.223	0.210	13	9	
" 18	0.223	0.203	10	10	
" 18	0.223	0.210	10	8	
" 19	0.223	0.203	10	10	
" 19	0.223	0.210	10	8	Taken as threshold
" 19	0.195	0.173	10	9	
" 20	0.195	0.173	10	9	
" 20	0.192	0.173	10	7	
" 21	0.195	0.173	10	8	
" 21	0.192	0.173	10	9	
" 22	0.200	0.173	10	9	
" 22	0.190	0.173	10	7	
" 23	0.200	0.173	10	9	
" 23	0.190	0.173	15	11	Taken as threshold
1915					
Mar. 4	0.780	0.520	20	19	
" 5	0.780	0.538	10	10	

TABLE 2—*Continued*

Date 1914	Width (mm.) of striae on: Positive field	Negative field	Number of: Trials given	Correct responses	Remarks
Mar. 5	0.780	0.558	10	10	
" 6	0.780	0.577	10	10	
" 6	0.780	0.600	10	10	
" 8	0.780	0.624	10	9	
" 8	0.780	0.650	10	10	
" 9	0.780	0.678	10	10	
" 9	0.780	0.709	10	9	
" 10	0.780	0.709	10	8	
" 10	0.780	0.723	10	8	
" 11	0.780	0.678	10	8	
" 11	0.780	0.729	10	8	
" 12	0.780	0.678	10	9	
" 12	0.780	0.731	10	10	
" 13	0.780	0.678	10	10	
" 13	0.780	0.743	10	8	
" 14	0.780	0.678	10	10	
" 14	0.780	0.750	10	7	
" 15	0.780	0.678	10	10	
" 15	0.780	0.750	10	7	Taken as threshold
" 16	0.975	0.780	10	9	
" 16	0.918	0.780	10	10	
" 17	0.867	0.780	10	9	
" 17	0.848	0.780	10	9	
" 18	0.867	0.780	10	10	
" 18	0.839	0.780	10	9	
" 19	0.867	0.780	10	9	
" 19	0.830	0.780	10	9	
" 21	0.867	0.780	10	10	
" 21	0.822	0.780	10	9	
" 22	0.867	0.780	10	10	
" 22	0.813	0.780	10	10	
" 23	0.867	0.780	10	9	
" 23	0.805	0.780	10	9	
" 25	0.867	0.780	10	9	
" 25	0.805	0.780	10	9	
" 26	0.867	0.780	10	9	
" 26	0.796	0.780	10	6	
" 27	0.867	0.780	10	9	
" 27	0.796	0.780	10	6	Taken as threshold

If the reader will now examine the daily records of Chick 2 and Monkey 2, shown in tables 1 and 2 respectively, he may observe that the chick was usually disturbed when he was required to avoid a field which he had recently been in the habit of choosing. The records for 21 to 24 March, 1914, exhibit this fact strikingly. Monkey 2 tended to respond in this way in the earlier stages of the work, but later overcame the tendency. On December 8, 1914, I made a control test which tends to make the fact clear. In the week immediately pre-

ceding this test I had required him to choose a field each stripe on which was 0.312 mm. wide, and to reject a field each stripe on which was 0.284 mm. wide. He chose correctly in 48 out of 50 trials. In this control test I presented the 0.284 mm. system ten times with a system each member of which was 0.312 mm. wide, and ten times with a system each member of which was 0.260 mm. wide. The animal was required to choose the coarser system at each trial, thus choosing the 0.284 mm. system ten times and rejecting it ten times in the same daily series. The results are shown in table 3.

TABLE 3

Trial	Width (mm.) of striae on Positive field	Width (mm.) of striae on Negative field	Relative position of positive field	Field chosen by the animal	Remarks
1	0.312	0.284	Right	Right	Compared before choosing
2	0.312	0.284	Right	Right	" " "
3	0.312	0.284	Left	Left	" " "
4	0.284	0.260	Left	Left	" " "
5	0.284	0.260	Right	Right	" " "
6	0.284	0.260	Right	Right	" " "
7	0.312	0.284	Left	Left	" " "
8	0.312	0.284	Left	Left	" " "
9	0.284	0.260	Right	Right	" " "
10	0.284	0.260	Right	Right	" " "
11	0.312	0.284	Left	Left	" " "
12	0.312	0.284	Right	Right	" " "
13	0.312	0.284	Right	Right	" " "
14	0.284	0.260	Left	Left	" " "
15	0.284	0.260	Left	Left	" " "
16	0.284	0.260	Right	Right	" " "
17	0.312	0.284	Right	Left	Chose without comparing
18	0.312	0.284	Right	Left	" " "
19	0.284	0.260	Left	Left	" " "
20	0.284	0.260	Left	Left	" " "

The animal was punished for choices 17 and 18. He had usually shown a preference for the left-food-compartment. In trials 17, 18, 19, and 20 he inspected the left field only. The field presented on that side at these trials was the field which he had correctly chosen in trials 14, 15 and 16. At trials 1 to 16, inclusive, he inspected both fields before choosing, and in every case he selected the relatively coarser system, regardless of the absolute width of its members. I believe that this animal could have been adapted by training to study by the standard method of right and wrong cases. Chick 2 gave no such promise.

The tendency of Chick 2 to respond by choosing or rejecting the familiar stimulus differs from the behavior of some birds used by Bingham,[5] which chose the larger of two circles and avoided the smaller without regard to the absolute size of the larger, and without regard to its previous association with reward or punishment. The comparison is worthy of mention as it seemingly points to an individual difference.[6] Bingham, however, gives no details which indicate how nearly unanimous or how consistent his birds were in manifesting this form of behavior.

AN INCIDENTAL OBSERVATION

One incidental feature of the behavior of Monkey 2 seems deserving of special mention. As was remarked above, I used a plate glass partition across the entrances of Alleys A^1 and A^2 of the Yerkes box. This partition contained two rather small holes through which the animal had to squeeze himself in order to enter the alley. On two occasions—June 16, 1914, and March 14, 1915, I neglected to insert this partition before giving the first trial of the daily series. On each occasion the animal refused to enter either alley. When I looked into the box to ascertain the cause of his delay in responding I found him groping in large semi-circles with his hands near the plane in which the glass partition belonged, and uttering frequent vocal exclamations. It was necessary to recall him to the home-compartment and insert the partition. It appeared from this behavior that he had become habituated to disregarding the partition as a visual object.

RELATIVE EASE OF DISCRIMINATION

In tables 4 and 5 I have summarized the values taken as "thresholds" for the two animals. The reader may see how these values were obtained by referring to tables 1 and 2, in which the animals' daily records appear. Whenever there

[5] Bingham, H. C. Size and form perception in *Gallus domesticus*. This journal, vol. 3, 1913, pp. 65 ff.

[6] Watson (Behavior p. 367) refers to the difference between the behavior of my chick and those of Bingham's as indicating that "this (Bingham's) observation cannot be confirmed." This interpretation is not mine. Had all the birds been worked on the same problem I should not have considered that the behavior of one bird was predictable from the behavior of a few others. But the two problems are so different that there is little basis for comparison.

seemed room for doubt whether the animal's errors were due to the magnitude of the stimulus-difference or to disturbance from some other cause, I presented a larger difference at a number of trials in the same daily series with the smaller difference. If all or most of the incorrect choices were made at the small stimulus-difference, I concluded that discrimination at that stimulus-difference was becoming difficult; if the animals' percentage of correct choices was low for the large stimulus-difference as well, I assumed that the source of disturbance was extraneous.

The values obtained on the two animals are not strictly intercomparable. In work on the monkey I reduced the stimulus-difference by smaller gradations than I could use in the work on the chick, owing to a limitation of the optical instrument by which the field was formed. As the angle of rotation of the gratings over each other becomes very small, as is the case where the width of the visible stripes thus formed is large, a very slight change in the angle of rotation makes a large difference in the width of the visible stripes. In the work on the monkey a larger angle and smaller gradations could be employed, since he was sensitive to much smaller widths than was the chick under similar conditions. I took for "threshold-differences" for the monkey the differences at which his average percentage of correct choices most nearly approximated 75. For the chick I took the stimulus-difference at which the first breakdown of discrimination not apparently due to disturbance from other causes occurred. This procedure is open to criticism in that I did not ascertain to what extent the bird could be made to overcome his uncertainty by continued training. At the time, however, this bird did not react well under punishment. As soon as the stimulus-difference became relatively small he usually refused to inspect both fields and adopted a position-habit. I recognized this defect in the procedure, and in a later piece of work attempted to settle the question.[7] I found that this bird could be made to improve to a limited extent after very long continued training. The degree of improvement which I was able to elicit is not sufficiently large to invalidate the results herein presented as the rough approximations of the

[7] Johnson, H. M. Visual pattern-discrimination in the vertebrates. IV. Effective differences in direction of visible striae for the monkey and the chick. To appear in this journal.

limits of the bird's discriminative ability which I regard them as being. It will be seen that the threshold-values for the chick vary irregularly from 33% to 42% of the width of the striae on the standard field. The variations may be explained by assuming that discrimination was difficult throughout this region of stimulus-differences. If the bird received punishment several times in close succession shortly after the difference approached this region, he "gave up" earlier, and yielded a larger "threshold" than if his errors were more widely distributed.

Table 5 also shows a great disparity between the "upper" and the "lower" threshold values given by the monkey when the width of the striae on the standard field was 0.520 mm. This fact pointed to a large effect of practice. The magnitudes of the thresholds obtained at the smaller values of the standard stimulus are so much lower than those obtained in the earlier stages of the work at the larger stimulus-values, that it was necessary to make a control test to discover if these differences were not due to the effect of training, instead of being a function of the absolute width of the striae. This test was made between March 4, 1915 and March 27, 1915. It shows quite clearly that the differences were due to the effect of training. The results suggest strongly that if training had been continued sufficiently long after the full effect of practice had been obtained, the values for all the difference-thresholds where the striae on the standard field were over 0.3 mm. wide would have borne a relation to the absolute width of the members of the standard system analogous to Weber's law for brightness. This relation probably does not hold for absolute widths below 0.2 mm., under these experimental conditions, since such fine systems become increasingly hard for the monkey to distinguish as striate. Due to pressure of other work and the small likelihood of Monkey 2 living through many more months, I did not feel justified in carrying this exploratory study farther at the time. Should a similar study ever be made, it would seem advisable to select fewer points at which to determine the animal's threshold, and to give a large number of presentations—several hundred, at least—of a number of differences in either direction from each point. In work on another problem with this animal I found such procedure quite fruitful.

TABLE 4

THRESHOLD CONDITIONS FOR CHICK 2

Width of striae on Positive field	Width of striae on Negative field	Difference per cent width on standard field	Mean of upper and lower thresholds	Remarks
*2.23 mm.	1.28 mm.	42	...	
1.30 "	*0.92 "	41	...	
*2.60 "	1.73 "	33	...	
*3.12 "	1.81 "	42	...	
1.44 "	*1.04 "	38	...	
1.04 "	*0.74 "	40	...	

TABLE 5

THRESHOLD CONDITIONS FOR MONKEY 2

1.774 mm.	*1.561 mm.	14		
*1.561 "	1.301 "	17	15.5	
0.890 "	*0.780 "	14		
*0.780 "	0.673 "	14	14	
0.610 "	*0.520 "	17		
*0.520 "	0.479 "	8	11.5	Note training-effect
0.413 "	*0.390 "	5.9		
*0.390 "	0.371 "	4.9	5.4	
0.321 "	*0.312 "	2.9		
*0.312 "	0.304 "	2.6	2.8	
0.232 "	*0.223 "	4		
*0.223 "	0.210 "	5.8	4.9	
0.190 "	*0.173 "	9.8	...	
0.796 "	*0.780 "	2		
*0.780 "	0.750 "	3.8	2.9	Note training-effect

* Standard stimulus.

COMPARISON WITH HUMAN SUBJECTS

A comparison of the relation between the absolute stimulus-value (expressed in terms of width of striae on the standard field) and the minimal effective differences for the animals with that obtained for human subjects is of some interest. Accordingly I determined this relation for two human subjects by means of the method of limits, using the same visual conditions as for the animals. The magnitudes of the thresholds obtained on the human subjects by the method of limits are not to be compared with those obtained by the discrimination-method on the animals. A threshold-value obtained by the method of limits

is generally smaller than one obtained under the same conditions by the method of right and wrong cases, of which the discrimination-method is a special and rough adaptation. The relation between the absolute value of the standard stimulus and a series of thresholds obtained by either method ought to vary in the same way. This comparison between the two sets of data is the only one which I wish to be made directly, although the values obtained for the monkey and for the human subjects indicate that their sensitivities are of the same order. The two human subjects were Dr. A. G. Worthing (W), a member of the research staff of this laboratory, and Mr. B. E. Shackelford (S), of the University of Chicago, late Brush fellow in this laboratory. Both observers are physicists possessed of a high degree of skill in optical pyrometry—one of the most difficult types of photometric measurements. Perhaps it should be remarked that both observers considered the visual conditions in the present experiment quite trying. An hour or more was usually required for making ten paired readings, which constituted a single sitting. The results are summarized in table 6.

TABLE 6

Width of striae on standard field (mm.)		Upper threshold in mm.	Lower threshold in mm.	Mean threshold per cent standard	Mean variation per cent mean threshold	Mean threshold for the two observers
0.780	W.	0.026	0.020	3.0	58	2.6
	S.	0.019	0.012	2.1	45	
0.390	W.	0.007	0.009	2.1	28	2.8
	S.	0.014	0.013	3.5	35	
0.260	W.	0.009	0.008	3.3	40	3.0
	S.	0.006	0.008	2.7	27	
0.195	W.	0.006	0.006	3.1	49	3.9
	S.	0.009	0.008	4.7	34	

The relation between absolute width and magnitude of the threshold for the animals and the two human observers is shown graphically in the accompanying figure. The average threshold for the two observers at each stimulus-value was taken merely for convenience in plotting on the scale selected.

SUMMARY

A very large effect of practice was found in the work on the monkey, which indicates the desirability of modifying the discrimination-method for use on the higher mammals.

When the full effect of practice has been obtained, Monkey 2, under optimal conditions, can distinguish differences in width of striae of less than 3%. These values are of the same order of magnitude as those obtained by the method of limits on two human observers possessed of unusual skill in photometry. Chick 2 ceased to discriminate when the difference in width of striae was reduced to a value between 33% and 42%. The relatively poor results of the chick were not due to errors of refraction, as both his eyes were emmetropic.

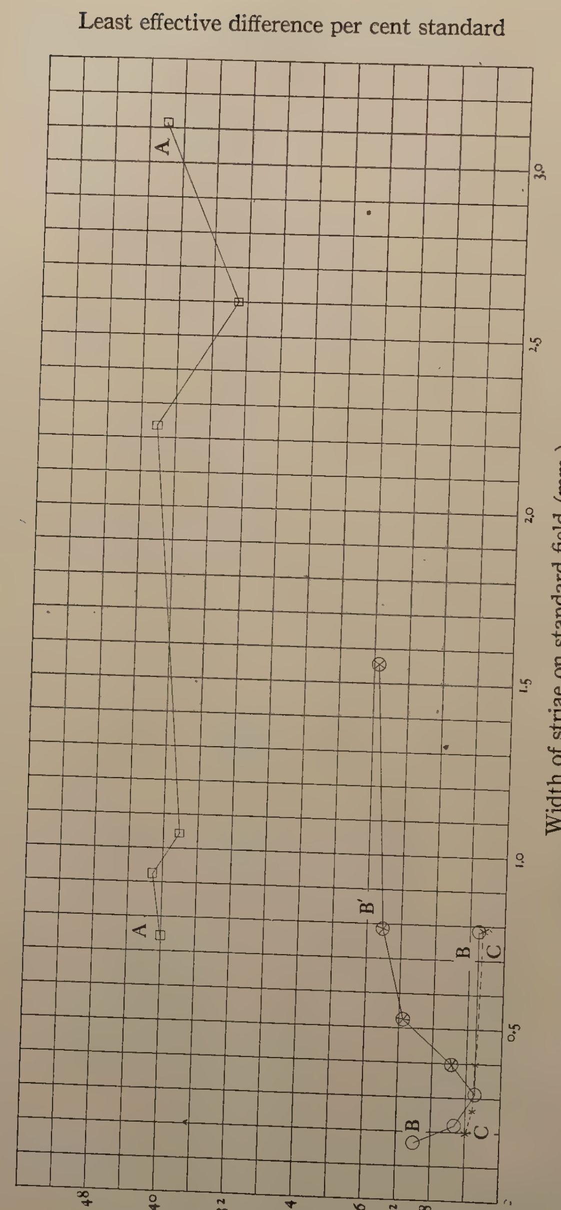
The discriminative ability shown by the monkey is on the average roughly ten times as great as that shown by Chick 2. His visual acuity, however, is only four to five times as good as that of the same bird. This disparity suggests that difference of width between two systems of visible striae constitutes a more difficult basis of discrimination for the chicken than the mere presence or absence of the striae. The fact that Chick 1 did not learn the problem, although width-difference was effective for him when presented with an ineffective difference in direction, lends support to this belief.

Nothing in the above work indicates that Chick 2 might not have yielded a lower threshold had training been sufficiently prolonged. A later experiment, however, indicates that the chick's susceptibility to improvement under prolonged training is not sufficiently large to affect the order of difference between his results and the monkey's which appears in this work.

For all the subjects, both human and animal, the relation between absolute size of detail and effective difference in size approximates an analog of Weber's law.

For the chick, familiarity was a more effective stimulus-characteristic than relative size of detail, and the bird never overcame the tendency to respond on that basis without continued retraining. The monkey eventually learned to respond on the basis of relative size. His results suggest that he is adaptable to study by a method of much greater precision than the method which was actually employed.

In conclusion I wish to thank Dr. P. W. Cobb for the work of refracting the eyes of the animals, and for making the photometric determinations for me; also, Dr. A. G. Worthing and Mr. B. E. Shackelford for their cheerfulness in undertaking the tedious observations.



Curve A: Threshold values for Chick 2
Curve B′: Mean threshold values for Monkey 2, early stages of training
Curve B: Mean threshold values for Monkey 2, later stages of training
Curve C: Mean threshold values for two human observers

VISUAL PATTERN-DISCRIMINATION IN THE VERTEBRATES—IV

EFFECTIVE DIFFERENCES IN DIRECTION OF VISIBLE STRIAE FOR THE MONKEY AND THE CHICK

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The purpose of the experiments described below was to ascertain how small a difference in direction of two regular systems of visible striae will condition the responses of animals possessing eyes of different types. In this work I used the "discrimination method" described by Yerkes and Watson,[1] feeding the animal in a compartment of the training box indicated by the "positive" test-object, and punishing him for attempting to enter the food-compartment indicated by the "negative" test-object. A detailed description of the method of training and of preparing the stimuli has appeared in an earlier report.[2] In the present work the discriminands were two circular fields, 6 cm. in diameter and 6.24 candles per square meter in brightness. The energy-distribution in the visible spectrum approximated that of a tungsten lamp operated at a specific consumption of 1.25 watts per candle. Both fields were covered with alternate dark and bright striae equal in width and separation. The chicks and the monkey had previously demonstrated their ability to react with perfect accuracy under the experimental conditions to the presence or absence of the striae from the test-field. The striae on the positive field were horizontal; those on the negative field deviated from the horizontal direction by a definite and variable amount. In the beginning of the training the difference was 90°, and was decreased by small gradations after the animal had formed the habit of invariably choosing the food-box indicated by the positive test-field.

[1] Yerkes, R. M. and Watson, J. B. Methods of studying vision in animals. *Behavior Monographs*, vol. 1, no. 2, 1911.

[2] Johnson, H. M. Visual pattern-discrimination in the vertebrates. I and II. This journal, vol. 4, 1914, pp. 319-361.

THE ANIMALS USED

The four animals used in the present study were described in the earlier report just cited, and were therein designated severally as Dog 1, Monkey 2, and Chicks 1 and 2. Dog 1 failed to learn the problem. This experiment is a part of a special study of that animal's vision. His results are interesting only when considered in connection with those obtained in the other work, so I shall reserve them for a separate report.[3] Chick 1 also failed to learn the problem in 800 trials. He had a large refractive error (1.5 D. hyperopia) in the right eye, and was also very easily excited by punishment or by unusual noise, so that he would refuse to work in the experiment-box. Eventually he was blinded in the left eye during a fight, and I did not resume experimentation on him. On account of lack of space I shall not include his daily records in this report. Chick 2, both of whose eyes were emmetropic, had distinguished as striate a system each member of which was 0.78 mm. wide at a distance of 60 cm. from the eye; the width under threshold-conditions for Monkey 2 being 0.163 mm. at the same distance. Chick 2 had also yielded a difference threshold for width of visible striae of 33% to 42%, and Monkey 2, a series of thresholds as low as 3% under optimal conditions.

In the course of the work some serious interruptions occurred. In September, 1914, Chick 2 acquired a severe white diarrhoea, and became greatly weakened. He finally refused to eat, and all the masculine characteristics of his behavior disappeared. I transferred him to an out-door yard where he had plenty of range. He showed improvement in a few days, and made a complete recovery in three months. Meantime his comb grew very large and depended over the left eye, largely occluding the visual field on that side. I amputated the comb March 6, 1915, and resumed retraining on the 10th. On the 20th he became engaged in a fight and was nearly killed. Other uncontrollable conditions then intervened and prevented the resumption of work until June 16, 1915.

Monkey 2—a frail and probably tubercular little animal—also sickened May 21, 1915. He refused food and in two days became too weak to stand alone. I moved him to a room where

[3] Johnson, H. M. Visual pattern-discrimination in the vertebrates. V. A demonstration of the dog's deficiency in detail-vision. To appear in this journal.

he could be kept in direct sunlight most of the day, and used forcible feeding on milk and raw eggs for ten days, during which time his condition began to improve rapidly. He became quite wild as a result of such handling, and I dared not resume work with him until June 15, 1915. On August 1 following, he fell from a steam-pipe six feet from the floor and sustained a partial fracture of the right femur and the left tibia. He made a fair recovery, but is still occasionally excited by unusual handling.

While these accidents render the results somewhat ragged in appearance, they occurred after the preliminary training had been completed. They probably do not affect the validity of the results.

RELATIVE EASE OF LEARNING

The daily records for the two animals appear in tables 1, 2-A and 2-B. They show a striking difference in the relative ease with which the animals learned the problem. Chick 2 required 585 trials, distributed over 58 days, to establish a habit of highly accurate choosing. It should be noted, however, that the bird showed consistent improvement in less than 400 trials. The average percentage of correct responses for the 195 trials given between July 12 and August 17 is 87. The monkey, on the other hand, learned the problem in the first daily series of 20 trials, during which he made only two incorrect responses. In learning the first problem—that of plain vs. striate discrimination, the chicken required only 214 trials for establishing a perfect habit, and the monkey required 312.

TABLE 1

Record of Monkey 2

Width of striae on both fields: 0.780 mm.
Mean brightness of both fields: 6.24 candles per sq. meter
Direction of striae on positive (standard) field: horizontal

Date 1915	Deviation from horizontal of striae on negative field	No. of trials given	No. of correct responses	Remarks
May 18	—90°	20	18	Incorrect choices, trials 1 and 9
" 20	—90°	20	20	Not worked on days for which no record is given
June 15	—90°	30	26	Very inattentive first 10 trials
" 16	—90°	20	20	
" 17	—90°	20	19	

TABLE 1—*Continued*

Date 1915	Deviation from horizontal of striae on negative field	No. of trials given	No. of correct responses	Remarks
June 18	—90°	20	18	
" 19	—90°	20	20	
" 20	—90°	20	20	
" 21	—90°	20	20	
" 22	—90°	10	10	
" 22	—75°	10	10	
" 23	—90°	10	10	
" 23	—60°	10	10	
" 24	—90°	10	10	
" 24	—45°	10	10	
" 25	—90°	10	10	
" 25	—30°	10	10	
" 26	—90°	10	10	
" 26	—15°	10	2	Very inattentive and slow
" 27	—90°	10	10	
" 27	—30°	10	10	
" 28	—30°	10	8	
" 28	—25°	10	10	
" 29	—30°	10	10	
" 29	—20°	10	5	
" 30	—30°	10	9	Up to this series most choices were made without comparison; tendency to compare from today on
" 30	—20°	10	7	
July 1	—30°	10	10	
" 1	—20°	10	9	
" 2	—30°	10	10	
" 2	—20°	10	9	
" 3	—20°	5	5	
" 3	—15°	15	15	Only records from today on are summarized in table 4
" 6	—15°	10	10	
" 6	—10°	10	7	
" 7	—15°	10	10	
" 7	—10°	10	6	
" 8	—14°	10	9	
" 8	—13°	10	10	
" 9	—13°	20	13	
" 10	—13°	20	16	
" 11	—15°	10	9	
" 11	—13°	10	9	
" 12	—15°	20	18	
" 13	—15°	5	4	
" 13	—12°	15	14	
" 14	—15°	5	4	
" 14	—12°	15	15	
" 15	—15°	5	5	
" 15	—11°	13	12	Removed after trial 18
" 16	—15°	5	5	
" 16	—10°	15	14	
" 17	—15°	5	5	
" 17	—9°	15	14	
" 18	—15°	5	4	
" 18	—8°	15	13	

TABLE 1—*Continued*

Date 1915	Deviation from horizontal of striae on negative field	No. of trials given	No. of correct responses	Remarks
July 19	—8°	20	18	
" 20	—8°	5	4	
" 20	—7°	15	15	
" 21	—7°	20	18	
" 22	—7°	5	4	
" 22	—6°	15	13	
" 23	—6°	20	19	
" 24	—6°	5	4	
" 24	—5°	15	12	
" 25	—5°	20	15	
" 26	—10°	5	5	
" 26	—5°	15	9	
" 29	+30°	10	10	Records from today to Aug. 9 inclusive not summarized in table 4
" 29	+25°	10	10	
" 30	+20°	10	10	
" 30	+15°	10	7	
" 31	+15°	20	15	
Aug. 1	+15°	20	14	Sustained severe injury in fall just following this series
" 8	+20°	20	18	Still quite lame; responses slow
" 9	+20°	20	18	
" 10	+20°	10	10	Condition improved
" 10	+15°	10	8	
" 11	+19°	10	10	More active
" 11	+18°	10	10	
" 12	+17°	10	10	
" 12	+16°	10	9	
" 13	+15°	10	8	Active
" 13	+14°	10	9	
" 14	+14°	10	10	
" 14	+13°	10	9	
" 15	+13°	10	10	
" 15	+12°	10	9	
" 16	+12°	10	8	
" 16	+11°	10	9	
" 17	+11°	10	9	
" 17	+10°	10	9	
" 18	+10°	20	17	Very active
" 19	+9°	20	18	
" 20	+8°	20	19	
" 21	+7°	20	14	Was frightened during this test; became wild and remained so for 3 weeks
" 21	+8°	20	17	
" 22	+8°	20	14	
" 23	+8°	20	14	
" 24	+10°	6	4	
" 24	+20°	14	14	
" 25	+15°	10	10	
" 25	+10°	10	7	
" 26	+12°	20	16	
" 27	+12°	20	20	
" 28	+12°	10	10	

TABLE 1—*Continued*

Date 1915	Deviation from horizontal of striae on negative field	No. of trials given	No. of correct responses	Remarks
Aug. 28	+11°	10	9	
" 29	+11°	20	17	
" 30	+11°	10	9	
" 30	+10°	10	7	
" 31	+10°	20	17	
Sept. 1	+10°	20	15	
" 2	+10°	20	19	
" 3	+10°	20	12	
" 6	+10°	22	17	
" 7	+10°	20	14	Retraining considered necessary
" 9	+15°	20	20	
" 10	+15°	20	20	
" 11	+15°	20	19	
" 12	+15°	20	20	
" 13	+15°	20	20	
" 14	+12°	20	19	
" 15	+11°	20	20	
" 16	+10°	10	7	Distracted by noise outside
" 17	+12°	20	15	
" 18	+12°	10	10	
" 18	+10°	10	10	
" 19	+12°	10	10	
" 19	+10°	10	10	
" 23	+12°	20	19	
" 24	+10°	20	20	
" 25	+9°	20	18	
" 26	+9°	20	20	
" 27	+9°	20	17	
" 28	+9°	20	19	
" 29	+8°	20	20	
" 30	+7°	20	19	
Oct. 1	+7°	20	14	
" 7	+7°	20	17	
" 8	+7°	20	15	
" 9	+6°	20	15	
" 10	+6°	20	18	
" 11	+6°	20	18	
" 12	+6°	20	20	
" 13	+5°	20	20	
" 14	+5°	20	18	
" 15	+5°	20	18	
" 16	+5°	20	17	
" 17	+4°	20	16	
" 18	+4°	20	15	
" 19	+4°	20	16	
" 20	+4°	20	15	
" 21	+4°	20	17	
" 22	+3°	20	14	
" 23	+3°	20	12	
" 24	+3°	20	17	
" 25	+3°	20	17	
" 26	+3°	20	16	
" 27	+2°	20	12	

TABLE 1—*Continued*

Date 1915	Deviation from horizontal of striae on negative field	No. o trials given	No. of correct responses	Remarks
Oct. 29	+2°	20	17	
" 30	+2°	20	16	
Nov. 2	+2°	20	16	
" 3	+2°	20	14	
" 4	+1°	20	12	
" 5	+1°	20	11	
" 6	+1°	20	11	
" 7	+1°	20	12	
" 8	+1°	20	15	

TABLE 2-A

RECORD OF CHICK 2

Mean brightness of both fields: 6.67 candles per square meter

	Positive field		Negative field			
Date 1914	Width of striae (mm.)	Angular deviation from horizontal	Width of striae (mm.)	Angular deviation from horizontal	No. of trials given	No. of correct responses
May 21	1.56	0°	1.56	90°	10	5
" 22	1.56	0°	1.56	90°	10	3
" 23	1.56	0°	1.56	90°	10	7
" 24	1.56	0°	1.56	90°	10	7
" 26	1.56	0°	1.56	90°	10	7
" 27	1.56	0°	1.56	90°	10	6
" 28	1.56	0°	1.56	90°	10	7
" 29	1.56	0°	1.56	90°	10	6
June 7	1.56	0°	1.56	90°	10	6
" 8	1.56	0°	1.56	90°	10	7
" 9	1.56	0°	1.56	90°	10	6
" 10	1.56	0°	1.56	90°	10	6
" 11	1.56	0°	1.56	90°	10	7
" 12	1.56	0°	1.56	90°	10	7
" 14	1.56	0°	1.56	90°	10	6
" 15	1.56	0°	1.56	90°	10	5
" 16	1.56	0°	1.56	90°	10	5
" 17	1.56	0°	1.56	90°	10	9
" 18	1.56	0°	1.56	90°	10	9
" 19	1.56	0°	1.56	90°	10	7
" 20	1.56	0°	1.56	90°	10	6
" 21	1.56	0°	1.56	90°	10	5
" 22	1.56	0°	1.56	90°	10	8
" 23	1.56	0°	1.56	90°	10	7
" 28	1.56	0°	1.56	90°	10	4
" 29	1.56	0°	1.56	90°	10	7
" 30	1.56	0°	1.56	90°	10	7
July 1	1.56	0°	1.56	90°	10	7
" 2	1.56	0°	1.56	90°	10	7
" 3	1.56	0°	1.56	90°	10	7

TABLE 2-A—*Continued*

Date 1914	Positive field: Width of striae (mm.)	Positive field: Angular deviation from horizontal	Negative field: Width of striae (mm.)	Negative field: Angular deviation from horizontal	No. of trials given	No. of correct responses
July 4	1.56	0°	1.56	90°	10	8
" 5	1.56	0°	1.56	90°	10	9
" 6	1.56	0°	1.56	90°	10	7
" 7	1.56	0°	1.56	90°	10	5
" 8	1.56	0°	1.56	90°	10	6
" 9	1.56	0°	1.56	90°	10	8
" 10	1.56	0°	1.56	90°	10	6
" 11	1.56	0°	1.56	90°	10	8
" 12	1.56	0°	1.56	90°	10	6
" 13	1.56	0°	1.56	90°	10	10
" 14	1.56	0°	1.56	90°	10	9
" 15	1.56	0°	1.56	90°	10	10
" 16	1.56	0°	1.56	90°	10	9
" 17	1.56	0°	1.56	90°	10	8
" 18	1.56	0°	1.56	90°	10	8
" 19	1.56	0°	1.56	90°	5	3
" 21	1.56	0°	1.56	90°	10	7
" 22	1.56	0°	1.56	90°	10	9
" 23	1.56	0°	1.56	90°	10	10
" 24	1.56	0°	1.56	90°	10	8
Aug. 12	1.56	0°	1.56	90°	10	9
" 13	1.56	0°	1.56	90°	10	10
" 14	1.56	0°	1.56	90°	10	8
" 15	1.56	0°	1.56	90°	20	17
" 16	1.56	0°	1.56	90°	10	10
" 17	1.56	0°	1.56	90°	10	9
" 18	1.56	0°	1.56	90°	10	10
" 19	1.40	0°	1.40	90°	10	9
" 20	1.30	0°	1.30	90°	10	10
" 21	1.20	0°	1.20	90°	10	9
" 23	1.11	0°	1.11	90°	10	8
" 24	1.11	0°	1.11	90°	10	7
" 24	1.04	0°	1.04	90°	10	9
" 25	1.56	0°	1.56	90°	6	3
" 25	1.11	0°	1.11	90°	5	5
" 25	0.98	0°	0.98	90°	10	8
" 26	1.30	0°	1.30	90°	3	3
" 26	1.11	0°	1.11	90°	5	5
" 26	0.92	0°	0.92	90°	15	7
" 27	1.30	0°	0.10	0°	5	5
" 27	1.40	0°	0.10	0°	10	10
" 27	1.04	0°	0.10	0°	10	9
" 29	1.30	0°	0.10	0°	10	10
" 29	1.04	0°	0.10	0°	5	5
" 29	0.98	0°	0.10	0°	10	8
" 30	1.11	0°	0.10	0°	5	5
" 30	0.98	0°	0.10	0°	10	8
" 30	0.92	0°	0.10	0°	10	10
" 31	1.04	0°	0.10	0°	5	5
" 31	0.98	0°	0.10	0°	10	9
" 31	0.87	0°	0.10	0°	10	6

TABLE 2-B

RECORD OF CHICK 2

Width of striae on both fields: 1.561 mm.
Mean brightness of both fields: 6.24 candles per sq. meter
Direction of striae on positive (standard) field: horizontal

Date 1915	Deviation from horizontal of striae on negative field	No. of trials given	No. of correct responses	Remarks
June 16	—90°	10	10	Retraining records of 10-19 March omitted
" 17	—90°	20	13	
" 21	—90°	20	18	Not worked on days for which no record is given
" 22	—90°	20	19	
" 23	—90°	20	20	
" 24	—90°	20	17	
" 25	—90°	20	19	
" 26	—90°	10	3	
" 27	—90°	10	9	
" 28	—90°	20	20	
" 29	—90°	20	19	
" 30	—90°	20	16	
July 1	—90°	20	18	
" 2	—90°	20	19	
" 3	—90°	20	18	
" 6	—90°	20	15	
" 7	—90°	20	20	
" 8	—80°	20	20	
" 9	—75°	20	20	
" 10	—70°	20	20	
" 11	—65°	20	16	
" 12	—65°	20	19	
" 13	—60°	20	17	
" 14	—60°	20	20	
" 15	—55°	20	18	
" 16	—50°	20	18	
" 17	—45°	20	17	
" 18	—45°	20	18	
" 19	—40°	10	6	Removed after tenth trial
" 20	—40°	15	9	Very excitable
" 21	—60°	20	16	
" 22	—60°	15	7	
" 23	—90°	20	14	Very excitable; responses slow
" 26	—90°	20	16	
" 27	—90°	15	14	Very slow
" 28	—90°	20	19	Slow
" 29	—90°	20	17	
" 30	—90°	5	5	
" 30	—60°	15	14	Active
" 31	—60°	20	18	Active
Aug. 1	—60°	10	10	
" 3	—60°	10	9	
" 3	—55°	10	8	
" 6	—55°	10	10	
" 6	—50°	10	8	
" 7	—50°	20	17	
" 8	—50°	10	9	
" 8	—45°	10	7	

TABLE 2-B—*Continued*

Date 1915	Deviation from horizontal of striae on negative field	No. of trials given	No. of correct responses	Remarks
Aug. 9	—50°	10	9	
" 9	—45°	10	9	
" 10	—50°	5	5	
" 10	—45°	15	11	
" 11	—50°	10	8	
" 11	—45°	10	10	
" 12	—45°	10	10	
" 12	—40°	10	10	
" 13	—40°	20	18	
" 14	—40°	20	16	
" 15	—45°	5	3	Very excitable
" 16	—45°	10	10	
" 16	—40°	20	12	
" 16	—50°	5	5	
" 19	+90°	20	18	
" 20	+75°	20	19	
" 22	+60°	20	20	
" 23	+55°	20	19	
" 24	+50°	20	19	
" 25	+50°	20	20	
" 27	+50°	10	9	Rather slow
" 27	+45°	10	10	
" 28	+45°	20	18	
" 30	+45°	30	24	
" 31	+45°	10	8	
" 31	+40°	10	7	
Sept. 2	+40°	20	17	
" 3	+40°	20	19	
" 6	+40°	20	16	Refused to work 4th and 5th trials
" 7	+40°	10	9	
" 7	+35°	10	7	
" 9	+35°	20	18	
" 10	+35°	20	17	
" 11	+35°	20	18	
" 12	+30°	20	13	
" 13	+30°	20	15	
" 14	+30°	20	18	
" 15	+30°	20	18	
" 16	+30°	20	17	
" 18	+25°	20	13	
" 19	+25°	20	15	
" 23	+25°	20	13	
" 24	+25°	20	16	
" 25	+25°	20	14	
" 27	—40°	20	17	
" 28	—40°	20	13	
" 29	—40°	20	16	
" 30	—40°	20	14	
Oct. 7	—40°	20	10	

AN ALTERNATIVE METHOD OF TESTING VISUAL ACUITY

A very convenient measure of an animal's visual acuity is the angle subtended at the eye by a single dark or bright stripe in a system which the animal can just distinguish as striate at a given distance. In the earlier experiments mentioned above, I obtained this value by training the animal to distinguish a striate field from a plain field at a distance of 60 cm. from the eye, and then reduced the width of the striae on the positive field until discrimination ceased. An alternative method consists in training the animal, as I did in the present work, to discriminate between a horizontal and a vertical system of equal width, and then gradually reducing the width of the striae in both systems simultaneously until the animal ceases to discriminate at the given distance. The work of Casteel[4] suggests this possibility, although Casteel did not attempt to control the factor of distance or to ascertain the limits of the animal's sensitivity. A priori, we should not expect the results yielded by the two methods to differ greatly, provided the animal's eyes were free from astigmatism in the vertical or horizontal direction, and provided otherwise that in both cases the animal is responding by choosing the positive field, rather than by rejecting the negative field. If experimental data confirm this expectation, and if the second problem should prove as easy for an untrained animal to learn as the first, the time required for learning the first problem might as well be saved. I decided to test the practicability of this method on Chick 2. The daily results appear in table 2-A, between the dates of August 18 and August 26, 1914. From August 27 to August 31 inclusive I repeated the test by the first method used—that of plainstriate discrimination, which is designated as method No. 1, and the other as method No. 2. In these tests, the minimal distance between test-field and eye at which comparison could be made without a choice being registered was 60 cm. The results are summarized in table 3. The values given under the heading "Width of striae (mm.)" are the widths of striae on the positive field for method No. 1, in which the striae on the negative field were invisibly small, and the widths of the striae on both fields in method No. 2, in which the difference in direction was 90°.

[4] Casteel, D. B. Discriminative ability of the painted turtle. This journal, vol. 1, 1911, pp. 1 ff.

TABLE 3

Width of striae (mm.)	Method No. 1: No. of trials given	Method No. 1: No. of correct responses	Method No. 2: No. of trials given	Method No. 2: No. of correct responses
1.56	..	..	106	94
1.40	..	..	10	9
1.30	5	5	13	13
1.20	..	..	10	9
1.11	25	25	30	25
1.04	20	19	10	9
0.98	30	25	10	8
0.92	10	10	15	7
0.87	10	6	..	..

These results indicate that the second method is feasible, and that uncertainty in choosing begins at nearly the same absolute stimulus-value whichever method is used. The relative ease of learning for the chick is decidedly in favor of method No. 1. Chick 1 failed to learn to discriminate when trained by method No. 2, but established a perfect habit in 443 trials when trained by method No. 1, despite numerous disturbing factors. Chick 2 learned by method No. 1 in 214 trials, as against 585 trials for method No. 2. The results given in table 3 should not be taken as indicating with accuracy where the bird's stimulus-threshold lies, as the training was interrupted too soon. I did not wish to risk spoiling the bird by frequent punishment for work on the main problem.

DIFFERENCE-THRESHOLD FOR DIRECTION

The term "threshold" is properly used to designate the mean between effectiveness and ineffectiveness of a stimulus or difference between stimuli, in producing a response. In the present discussion this mean is assumed to have been reached when the stimulus-difference is effective in half the total of a fairly large number of presentations or "trials." If the difference were wholly ineffective, the animal should be expected, on the theory of probability, to respond correctly in 50% of a large number of trials. If the difference were always effective, 100% of the responses should be correct. The stimulus-difference at which the percentage of correct choices is 75 is therefore taken as the animal's "threshold." The accuracy of such a determination is indicated by the consistency of the results. The measure of consistency used herein is the mean variation

of the percentage of correct choices for the daily series of trials from the average percentage of correct responses for the total number of trials at a given stimulus-difference.

In much of the past work on the special senses of animals carried on by means of training methods, the experimenters have trained the animals to respond to a given difference between the stimuli, and have then reduced the difference until the animals cease to discriminate. When a break-down occurs, the experimenters frequently discontinue the training after a few additional trials, and take the stimulus-value or stimulus-difference at the breakdown as the animal's "threshold." In some earlier work I followed this procedure, having observed that in some instances further training confused the animal and caused it to sulk. In the present work I have endeavored to find the degree to which such confusion can be overcome by continued training.[5] The results obtained on the chicken show a training-effect which is important, though not relatively large; while the final results obtained on the monkey yielded a threshold of a different order of magnitude from the stimulus-difference at which the first break-down occurred. As appears in table 1, in the records from August 22 on, the monkey showed a strong tendency to break down at a stimulus-difference of 8° to 10°; but he overcame this tendency after continued training, and eventually yielded a threshold in the neighborhood of 2°. Had I given the monkey a considerably larger number of trials at the stimulus-differences of —13°, —10°, +10°, +8° and +7°, after the full effect of training had been obtained, the average percentages of correct responses could be plotted against the stimulus-differences on a consistent and fairly smooth curve.

The results of Monkey 2 are summarized in table 4, and those of Chick 2 in table 5. In compiling the results for each stimulus-difference, I observed the following procedure: Having obtained the average percentage of correct responses for the total number of trials, I took the average percentage of correct responses for each daily series, and obtained the mean variation of these daily averages from the average for the group. Since 20 trials compose the standard daily series, I weighted the

[5] My adoption of this course is the result of an extensive discussion carried on with Professor Knight Dunlap some two years ago, regarding the validity of the discrimination-method, as the latter is usually employed.

variations from the mean of the individual daily averages according to the number of trials in the individual daily series referred to 20 as a basis. The mean variation of the averages of the daily series from the general average is expressed in units of the latter in tables 4 and 5, and it gives an indication of the consistency and hence the reliability of the results.

TABLE 4

RECORD OF MONKEY 2

Width of individual striae on both fields: 0.780 mm.
Mean brightness, both fields: 6.24 candles per sq. meter
Striae on positive (standard) field: horizontal

Deviation from horizontal of striae on negative field	No. of trials given	No. of correct responses	Average percentage of correct responses
—15°	95	89	93.7± 2.9
—14°	10	9	90.0
—13°	60	48	80.0± 7.5
—12°	30	29	96.7± 3.7
—11°	13	12	92.3
—10°	40	32	80.0± 7.5
—9°	15	14	93.3
—8°	40	35	87.5± 1.9
—7°	40	37	92.5± 3.7
—6°	40	36	90.0± 3.3
—5°	50	36	72.0± 6.0
+15°	130	126	96.9± 3.5
+14°	30	29	96.7± 4.3
+13°	20	18	90.0± 0.0
+12°	140	127	90.7± 6.0
+11°	80	73	91.1± 3.0
+10°	228	185	81.2± 8.3
+9°	100	92	92.0± 4.4
+8°	100	84	84.0±11.2
+7°	100	79	79.0± 8.8
+6°	80	71	88.7± 6.9
+5°	80	75	93.7± 6.7
+4°	100	79	79.0± 3.3
+3°	100	76	76.0± 8.8
+2°	100	75	75.0± 8.0
+1°	100	61	61.0± 5.6

TABLE 5

RECORD OF CHICK 2

Width of individual striae on both fields: 1.561 mm.
Mean brightness, both fields: 6.24 candles per sq. meter
Striae on positive (standard) field: horizontal

Deviation from horizontal of striae on negative field	No. of trials given	No. of correct responses	Average percentage of correct responses
—90°	400	345	86.2±10.0
—80°	20	20	100.
—75°	20	20	100.
—70°	20	20	100.
—65°	40	35	87.5± 7.5
—60°	130	111	85.4± 8.7
—55°	40	36	90.0± 3.3
—50°	90	79	87.7± 2.6
—45°	110	94	85.4± 6.4
—40°	195	141	72.3±11.4
+90°	20	18	90.
+75°	20	19	95.
+60°	20	20	100.
+55°	20	19	95.
+50°	50	48	96.0± 2.7
+45°	70	60	85.7± 5.8
+40°	80	68	85.0± 5.0
+35°	70	60	85.7± 4.3
+30°	100	81	81.0± 8.8
+25°	100	71	71 0± 5.2

AN APPARENT EFFECT OF "CONTRAST"

After I had obtained the threshold for deviation in the positive direction for Monkey 2, I gave him 40 trials—20 trials each on the 9th and 10th of November—in which the striae on the positive field were horizontal and those on the negative field deviated from the horizontal by 5° in the negative direction. Only 12 responses out of the 40 were correct, the animal persistently tending to choose the negative field against punishment. In this connection it should be noted that when the difference in direction is small and when the striae on one field are horizontal, if the two fields are regarded simultaneously, the striae on both fields appear to be inclined from the horizontal, but in opposite angular directions. For about six weeks previous to these control tests, the striae on the positive field, although really horizontal, appeared to the human observer to deviate in the negative direction, owing to the influence of the other field, whose striae were inclined slightly in the positive direction. If

we assume a similar "contrast-effect" for the monkey, we have a sufficient explanation of his behavior in these control tests.

SUMMARY

Three animals—a monkey and two chickens—previously trained under comparable conditions, showed a striking difference in their individual ability to acquire a perfect habit of response to difference in direction in two systems of visible striae. The monkey perfected his habit in the first series of 20 trials. One chick failed to learn the problem and another chick required 58 days and 585 trials to perfect the habit.

The work demonstrated the practicability of an alternative method of testing visual acuity, but suggested that for some animals the problem is so difficult as to make the method originally used by the author more desirable.

The monkey's difference-threshold for direction of elements of a pattern lies between 2° and 5°; and the chick's threshold between 25° and 40°. The magnitude of the thresholds within these limits for either individual depends in large part on the effect of training.

The training-records, as well as the final results, suggest that the characteristic of direction in visual objects has much more significance for the monkey than for the chicken.

The relative improvement brought about by training is very much greater for the monkey than for the chicken. This fact suggests that other differential factors than relative development of the sense-organ play an important part in discrimination of this type. The point is emphasized by the fact that the monkey's visual acuity, as shown in an earlier study, is between four and five times as good as that of the chick; while his sensitivity to difference in direction is from eight to twelve times as great.

VISUAL PATTERN-DISCRIMINATION IN THE VERTEBRATES—V

A DEMONSTRATION OF THE DOG'S DEFICIENCY IN DETAIL-VISION

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The experiments reported in this paper grew out of certain questions of especial personal interest to the author. These questions are of minor importance as compared with some general questions which the work involves, but as the former really determined the course of experimentation it seems well to mention them.

In the years between 1910 and 1912 the writer, then working at the Johns Hopkins University, acquired some dogs which had been rendered temporarily blind by having their eyelids scraped at the edges and stitched together during the first week of puppyhood. This operation caused the eyelids, which normally separate at about the ninth day, to grow tightly together; and they remained in this condition until they should be separated by a slight operation.

While these animals were blind[1] I trained each of them to open three "problem-boxes" by a single movement of the head, the teeth or the paw, within a minimal time (two seconds or less) and without making any useless movements. The manner of arranging and conducting these experiments is open to criticism, but the results indicate clearly that the blind dogs became quite as proficient as normal dogs trained under identical conditions, and that the number of trials necessary to the acquisition of skill is not consistently greater for blind dogs (Nos. 7 and 8) than for a normal dog (No. 6) of the same litter and trained in the same way. Also, the blind dogs, as well as the normal dogs, showed practically no loss of skill after sixty days of rest.

[1] Johnson, H. M. Audition and habit-formation in the dog. *Behavior Monograph*, no. 8, Cambridge, Mass., Henry Holt & Co., 1913.

After each of the blind dogs had learned to open three boxes in this way, the eyelids were parted by an operation. All the animals except Dog 7 showed an opacity of the cornea, usually slight in degree and extent, but varying in different individuals. Dog 7 did not exhibit an opacity. None of these animals showed marked changes of behavior after the operation. I then required Dogs 7 and 8 to learn three more problem-boxes each. They exhibited slightly greater proficiency in acquiring skill than they had shown while they were blind, but the improvement is due—at least in part—to the effect of practice, and is considerably less than that brought about wholly by practice in the case of the normal dog.[2]

These experiments demonstrated that the dog can get along surprisingly well without vision in making complicated adjustments. Other experiments indicated that even normal dogs did not react to some objects as if the latter were visually perceived, provided the objects were stationary.

While the foregoing experiments suggested that the dog may make little use of vision as we ordinarily think of it, they left the question open as to the kind and degree of vision which the dog may have. In 1911-12, I made an attempt to test the dog's sensitivity to difference of outline in visual objects. I used a single animal, designated as Dog 5 in the report cited. I made the tests in the psychological laboratory of the Johns Hopkins University, under the direction of Professor John B. Watson, using the Yerkes-Watson standard apparatus[3] and the discrimination-method recommended by these authors. The test-objects used were a circle 6 cm. in diameter and its (approximately) equivalent square. The animal was fed at the food-box under the square. He learned in about 1000 trials to choose the square invariably, but its brightness (and hence its luminous intensity) was four times that of the circle. When the brightness-difference was eliminated, the animal immediately ceased to show any preference for the square, and he did not make any consistent improvement in 600 trials. It became necessary to discontinue the work at this point. Shortly afterwards the

[2] The records of dog 6 (normal) and of dogs 7 and 8 (first blind and later with the eyelids separated) are intercomparable. The records of dogs 1 and 2 and of dog 5 are not.

[3] Yerkes, R. M. and Watson, J. B. Methods of studying vision in animals. *Behavior Monograph*, no. 2, Cambridge, Mass., Henry Holt & Co., 1911.

animal was accidentally killed. Meantime I had acquired no information regarding the refraction of his eyes. Consequently I did not feel justified in publishing the report of the work as containing anything decisive or important. It is of some interest when considered in connection with some later experiments described below.

Three years ago I became interested in the question of the relative visual sensitivity of animals possessing different types of retinal structure. The retina of the dog's eye is fairly typical of the mammals below the primates. There is no fovea,[4] rather indefinite "sensitive areas" and numerous opaque nerve-fibers which must be considered as blind spots. Such a retinal structure is characteristic, in the main, of mammals below the primates. It seemed fair to select the dog as a representative of this class. I chose the domestic chicken as representative of animals possessing a definite sensitive area but no fovea, and the Capuchin monkey as representative of animals possessing a fovea centralis, temporal to the entrance of the optic nerve. I also felt impressed by the apparent superiority of stimuli such as Casteel[5] used, over stimuli differing only in outline, for a test of the question in which I was particularly interested. I selected[6] as the stimulus to be chosen by the animal, a circular field, 6 cm. in diameter, covered by a system of horizontal dark and bright stripes of equal width. The number of stripes on the field and the width of each stripe could be varied by insensible gradations. The field to be rejected was covered by a similar system of striae, but the members were so numerous and so fine that the eye would not resolve them at the minimal distance at which the animal could make his choice. The stimuli differed in no other respect. The sensitivity of the animal was to be measured by the angle subtended at the eye by the separation of the upper edge of one bright stripe from the lower edge of the bright stripe just above it. The reader should consult the original report for details of these tests.

The daily results obtained for Dog 1, a pure-bred English

[4] Slonaker, J. R. A comparative study of the area of acute vision in vertebrates. *Journal of Morphology*, vol. 13, no. 3, 1897.

[5] Casteel, D. B. Discriminative ability of the painted turtle. This journal, vol. 1, 1911, pp. 1 ff.

[6] Johnson, H. M. Visual pattern-discrimination in the vertebrates. I and II. This journal, vol. 4, 1914, pp. 319-361.

bull-terrier, are shown on page 352 of that report. When the width of each stripe on the "positive" field was 5.2 mm., and the distance from the eye was 60 cm., the animal chose the positive field 36 times in 50 presentations or "trials". In the last 20 trials, 18 choices were correct. Believing at the time that he had learned the problem, I reduced the width of the stripes. On examining his subsequent daily records with these, I became convinced that the improvement was accidental, and due to a change in the animal's "position-preference" as a time when his right-left order of choosing happened to fit the order of presentation quite well. When the width of each stripe was 3.9 mm. the animal chose correctly in 127 cases out of 200; when it was reduced to 3.72 mm., 112 out of 175 choices were correct.[7]

These results did not show anything conclusive regarding the dog, except that working near the limit of the instrument I had not made a stimulus-difference large enough to be effective in 50% of the cases. (This condition would be met when 75% of a large number of responses were correct.)

The general method followed in these experiments had yielded quite definite and positive results in the work on the monkey and the chickens. The individual stripes composing the positive system had subtended a very large visual angle throughout all the work on the dog. The failure to obtain positive results on the dog raised several questions regarding the work.

Early in the training the animal had learned to choose the correct food-box by testing the electrodes at the entrance-alleys for electrical charge. When I eliminated this factor he showed great disturbance. It seemed advisable to use another individual, which had not been thus disturbed during the training. I selected a pure-bred female beagle-hound, four months old, for this purpose. Beginning May 26, 1914, I gave her ten trials daily for 90 days, using the method described in the work on Dog 1, the monkey and the chickens. She showed no consistent preference at any time for the positive field, each stripe on which was 5.2 mm. wide. The minimal distance between test-field and the eye at which a choice could be made was 50 cm. A detailed report of her work would be without value in view of facts which we later ascertained, and which I shall mention below.

[7] After the original report was prepared I resumed the work at this stimulus-value, and obtained a lower percentage of correct choices over 150 additional trials.

It now became necessary to determine whether the negative results which the dogs gave were due to the inappropriateness of the conditions under which the latter had worked. The first matter to be settled was that of errors of refraction in the dog's eyes. This examination should have been made before the experiments were begun, as is made evident by the results. My colleague, Dr. P. W. Cobb, was kind enough to make the examination and to assume responsibility for the results. He administered atropin to the animals for about a week, until the pupils ceased to respond to light. He then made a careful skiascopic examination. The results obtained during mydriasis were very consistent. Dog 1 showed about 0.25 to 0.50 D. hyperopia during mydriasis. (This condition is characteristic of the emmetropic human eye.) No astigmatism was discoverable. The examination without mydriasis yielded variable results, but none of them indicated the presence of a refractive error which the animal did not overcome by accommodation or by an analogous process. We assumed, therefore, that this dog's eyes were for practical purposes emmetropic. The correction for Dog 2 was +1.75 D. sphere with +0.75 cylinder, the axis lying in the horizontal meridian. The necessary correction was the same for both eyes. A week later Dr. Cobb attempted to test the animals for extent and range of accommodation, but got no consistently positive results. It seemed useless, therefore, to continue experimentation of Dog 2, since even the best accommodation could hardly have overcome so large a refractive error, and since it was inconvenient to equip her with spectacles.

At this time I was working some other animals on the problem of discriminating between a vertical system of striae and a horizontal system differing from the former only in direction. The problem had proved itself quite easy for some of the animals. I had also found it feasible to test an animal's visual acuity by making the stripes on both fields rather coarse, and training the animal to choose the food-box indicated by the horizontal system. The next step was to reduce the width of the stripes in both systems simultaneously, until the members became so numerous and their width and separation so small that the animal could not distinguish the horizontal system from the vertical system at the given distance. I decided to test Dog 1 by this method.

In this work I used the same experiment-box and test-objects and the same general technique as are described in the former report.[8] The mean brightness of each test-field was 6.2 candles per square meter. The width of each stripe in either system was 3.902 mm. The animal had to choose with the eye 40 cm. or more from the test-field, and he was fed in the food-box indicated by the horizontal system. I gave him 20 trials each day. In 140 trials the animal chose correctly only 75 times, and showed no tendency to improve. There seemed reason to question whether he was capable of discriminating between purely visual objects, and of demonstrating the fact by acquiring a perfect habit. Professor Mast, with whom I discussed the question, urged me to settle the point. On June 24, 1915, I gave the animal 20 trials in which only the positive test-object was presented. He was fed in the box at which it appeared. All 20 choices were correct, and there was no hesitation at any time. On the following day I reintroduced the negative field, but stopped it down, so as to introduce a difference in area in addition to the difference in pattern. Hitherto, each field had been limited by a circular diaphragm 6 cm. in diameter. Over the diaphragm limiting the negative field I now slipped a smaller diaphragm, the opening of which was concentric with that of the former. The animal's daily records for the various differences in area appear in table 1. The results show that the dog is able to discriminate when the difference of area presented is between the ratios of 2.25 to 1 and 1.44 to 1. On July 24, August 1, August 14 and August 31 I made control-tests, in which the width of the striae on both fields was so reduced that the fields appeared of uniform brightness to the human eye. As will be seen in the table, these tests showed that the dog's behavior was not affected by the presence or absence of the stripes. After the animal had ceased to discriminate, when the stimuli was a 6 cm. circle and a 5 cm. circle, I retrained him for six days, beginning August 30, 1915, requiring him to choose the 6 cm. circle and to reject the 3 cm. circle. Both fields were of uniform brightness. His average percentage of correct choices for the 120 trials was 85.8. I then reduced the brightness of the 6 cm. circle by introducing an absorption-

[8] In the present work I placed a copper tray, holding a moistened felt pad, between the exit-door of the home-box and the alleys entering the food-boxes. This tended to reduce the variability of the resistance of the animal's feet to a minimum.

TABLE 1—RECORD OF DOG 1

Width of striae (mm.) Deviation from horizontal Diameter of field (cm.)	+ field 3.9 0° 6	— field 3.9 90° 1	+ field 3.9 0° 6	— field 3.9 90° 2	+ field 3.9 0° 6	— field 3.9 90° 3	+ field 3.9 0° 6	— field 3.9 90° 4	+ field 3.9 0° 6	— field 3.9 90° 5	Mean brightness, both fields: 6.2 candles per square meter
Date	No. trials given	No. correct responses	No. trials given	No. correct responses	No. trials given	No. correct responses	No. trials given	No. correct responses	No. trials given	No. correct responses	Remarks
June 25	20	12									
" 26	20	16									
" 27	20	15									
" 28	20	15									
" 29	20	13									
" 30	20	19									
July 1	20	12									
" 2	20	17									
" 3	20	18									
" 6	20	17									Not worked on days for which no record is given
" 7	20	16									
" 8	20	19									
" 9	20	16									
" 10	20	17									
" 11	20	17									
" 12	20	17									
" 13	20	19									
" 14	20	16									
" 15	20	19									
" 16			20	13							
" 17			20	13							
" 18			20	14							
" 19			20	16							
" 20			20	18							

TABLE 1—RECORD OF DOG 1—*Continued*

Width of striae (mm.) / Deviation from horizontal / Diameter of field (cm.)	+ field 3.9 0° 6	− field 3.9 90° 1	+ field 3.9 0° 6	− field 3.9 90° 2	+ field 3.9 0° 6	− field 3.9 90° 3	+ field 3.9 0° 6	− field 3.9 90° 4	+ field 3.9 0° 6	− field 3.9 90° 5	Mean brightness, both fields: 6.2 candles per square meter
Date	No. trials given	No. correct responses	No. trials given	No. correct responses	No. trials given	No. correct responses	No. trials given	No. correct responses	No. trials given	No. correct responses	Remarks
July 21			20	18							
" 22			20	19							
" 23			20	18							
" 24			20	19							Considered ready for further control
" 25					20	15					Width of striae reduced to 0.1 mm.
" 26					20	10					Width of striae restored to 3.9 mm.
" 27					20	18					
" 28					20	18					Mr. R. Kerslake present.
" 29					20	16					Dr. A. H. Pfund present
" 30					20	17					Mr. F. W. Chapman present
" 31					20	19					
Aug. 1					20	20					Considered ready for further control
" 4							20	17			Width of striae reduced to 0.1 mm. Dr. W. E. Burge present.
" 6							20	15			Width of striae restored to 3.9 mm.
" 7							20	17			
" 8							20	18			
" 9							20	15			
" 10							20	16			
" 11							20	16			
" 12							20	16			Dr. L. O. Grondahl present
" 13							20	14			
" 14							20	16			
" 15							20	15			Considered ready for further control Width of striae reduced to 0.1 mm.

" 16.									20	12	Width of striae restored to 3.9 mm.
" 17.									20	13	
" 19.									20	14	
" 20.									20	14	
" 22.									20	12	
" 23.									20	13	
" 24.									20	14	
" 25.									20	14	
" 27.									20	15	
" 28.									20	12	Stimulus-difference regarded as subliminal
" 29.									20	15	Width of striae reduced to 0.1 mm. henceforth
" 30.					20	17					
" 31.					20	16					
Sept. 2.					20	20					
" 3.					20	15					
" 9.					20	17					
" 10.					20	17					Considered ready for further control
" 14.					20	9					Brightness of 6 cm. field reduced to 1.5 candles per square meter henceforth
" 15.					20	15					
" 16.					20	11					
" 18.					20	12					
" 19.					20	14					

screen, to about 25% of its original brightness. This made the areas of the two fields approximately inversely proportional to their brightnesses or, in other words, made them very nearly equal in luminous intensity. I gave the dog 100 trials under this condition, but obtained only 61 correct responses. This indicated that he had been merely choosing the field which sent the greater light-flux into his eye, and had not been affected by the difference in area except in so far as it had occasioned a difference in luminous intensity.

The foregoing results indicate with fair definiteness that the dog did not distinguish the large differences in pattern and in outline presented under the experimental conditions. We are not safe in drawing general conclusions from such evidence, however, as long as there is room for doubt whether a clear image of the test-fields had been formed on the retina. This question hinges on the ability of Dog 1 to accommodate. I have found but few references in the literature bearing on the question of the range of accommodation in the dog. Boden[9] remarks that Würdinger showed in 1886 that the dog has a ciliary muscle, and that the necessary mechanism for accommodation is therefore present. He adds that the question of the extent to which accommodation is actually accomplished is one over which opinions differ widely. He quotes Hensen and Völckers,[10] who worked on the mechanism of accommodation in young dogs, to the effect that the dog possesses a wide range of accommodatory change—as wide at least as the monkey's. On the other hand, he quotes Hess and Heine[11] as having elicited a change of refraction of only 1.0 to 1.5 D. by stimulating the sympathetic fibers electrically. Boden himself refracted the eyes of 100 dogs of both sexes and of various ages and breeds, both before and during mydriasis. In the examination without mydriasis he sometimes observed changes in the diameter of the pupillary opening when the dog appeared momentarily to fixate the mirror used in the examination. Boden suspected that an accommodatory movement accompanied this change, since occasionally the sharp image of the pattern which he projected on to the

[9] Boden, Rudolf. Ueber den Refraktionszustand des Hundeauges. *Arch. f. vergleichende Ophthalmologie*, vol. I, 1909-10, pp. 195-241.

[10] Cited by Hess. Anomalien d. Refraktion und Akkommodation d. Auges. Gräfe-Sämisch, Handbuch, 2 Auflage, p. 230.

[11] Hess and Heine. Gräfe-Sämisch, Handbuch, 2 Auflage, p. 236.

dog's retina would suddenly appear blurred under those conditions. He was unable to establish, however, whether these effects were the result of accommodation or were due to astigmatic refraction in the dog's eye.[12]

Dr. Cobb, in a later and more extensive skiascopic examination of Dog 1, without mydriatic, found occasional fluctuations of refraction, varying from 0.25 to 0.75 D. These fluctuations were seldom sustained for any considerable interval, and could not be elicited by moving the experimenter's fingers, or even food, to and fro before the dog's eye. While the most natural inference is that the fluctuations were due to accommodation, it would also be possible to account for them on other suppositions. It was impossible to control the dog's fixation, and rotation of the eyeball changed the length of the optical path. (This extended from the light-source to the mirror, thence through the comparison lens into the dog's eye and to the retina, thence back through the comparison lens to the experimenter's eye.) This change might be made by difference in angle of incidence at the dog's cornea, by differences in refractive index of the different layers of the dog's lens, and also by unevenness of contour of the dog's retina. It seemed clearly established, however, that parallel rays, or rays proceeding from an object 20 feet or more from the eye, are sharply focused on the retina of

[12] I have elsewhere asserted that the dog's mechanism of accommodation is useless unless it serves in some way to change the radius of curvature of the cornea, as is the case in some birds, but, according to Hess, is not true of the mammals. This assertion was based on my acceptance of a reference by an American writer to Freytag's work (Die Brechungsindices der Linse und der flüssigen Augenmedien bei der Katze und beim Kaninchen. *Arch. f. verg. Ophth.*, vol. I, 1909-10). In this reference Freytag is cited as saying that the refractive indices of the lens and of the fluid media of the dog's eye are practically identical, and that several other mammals suffer under the same condition. Since I made the above remark, I have procured a copy of Freytag's original article which before had been inaccessible to me. It appears that Freytag was incorrectly quoted by his reviewer. He actually gives as mean values of the refractive indices in young and old dogs: for the aqueous humor, 1.3349; for the vitreous humor, 1.33483; and for the lens, values ranging between 1.4498 and 1.4666, depending on age. He reports a comparable difference between the refractive indices of the lens and fluid media in all the mammals which he studied.

I am satisfied that some individual dogs make very little use of the mechanism of accommodation. If such is generally true, it would seem that the defect is retinal, rather than in the accommodatory apparatus itself. If it may be assumed that the stimulus to accommodation is indistinctness of the retinal image, it is evident that an animal whose retina is relatively insensitive to detail would have relatively slight stimulus to accommodation.

Incidentally, the solution of a number of extremely interesting problems in the relation between vision and field-behavior must await the determination of the range of accommodation in representative infra-primate mammals.

the unaccommodated eye of Dog 1. An object 133 cm. distant may be imaged on at least some parts of the retina if the animal accommodates or rotates the eye properly. In the discrimination work just described, the animal had to choose with the eye less than a meter from the test-fields, and he actually chose, as a rule, with the eye at the minimal distance, which in part of the work was 60 cm. and in the rest, 40 cm. There was some room for doubt, therefore, whether a clear image had been formed on the retina under the prescribed conditions. Further work was necessary to determine whether the dog's inability to discriminate was due to retinal insensitivity or to other causes.

I proceeded at once to modify the method so as to insure that a sharp image of the patterns to be discriminated would be formed on the retina of the animal's unaccommodated eye. There are several means by which this could have been accomplished. We could have mounted the test-objects 20 feet away, so that rays proceeding from each point on them would have reached the dog's eye as nearly parallel rays. But the test-objects are small, and might not have attracted the dog's attention. The largest striae which these particular gratings will form subtend a very small angle at 20 feet. Negative results thus obtained would have been ambiguous. Of course it would have been possible to project an enlarged image of the patterns on to a distant screen, but in such case modification of the Yerkes experiment-box would have been necessary. It would also have been possible to equip the dog with spectacles. Had this course been adopted it would have been necessary to use extreme care to insure that the animal inspected the test-object at a constant distance. This procedure involved some practical difficulties. Another course seemed most nearly free from objectionable features. I took two lenses, each having a free opening of 6 cm. and an equivalent focus of 40.8 cm., and mounted a test-object in the first principal focus of each of these lenses. Each of the two optical systems thus formed was mounted on a photometer bench, so that the face of the lens remote from the test-object was presented at the window (W_1, W_2, fig. 6, p. 338 of the first article of this series) of the Yerkes box. The axis of each optical system was normal to the plane of the window at which it was presented, and coincided with the center of the latter. The lenses are achromatised for two points in the visible

spectrum, and are highly corrected for spherical aberration, astigmatism, distortion and curvature of the image. With this arrangement light from all parts of the test-field emerged from the lens in bundles of parallel rays. The eyes of dog 1 being emmetropic, it follows from geometrical optics that if his unaccommodated eye were placed in any part of the cone of light emerging from the lens, a sharp image of the test-field would be formed on the retina, and that the angle subtended by the image of any stripe at the second nodal point of the eye would be the same as that subtended by the stripe itself at the first nodal point of the projection lens.

The stripes on the positive field were horizontal, and each one was 3.902 mm. wide. The distance between the test-field and the first nodal point of the lens was 399 mm.[13] The image of each stripe therefore subtended a visual angle of 33′ 32″—an angle larger than is subtended by the sun's disc at the earth. The pattern on the positive field is closely comparable with that of a plank fence, the units in which are 6 inches wide and 6 inches apart, viewed at a distance of 50 feet. The stripes on the negative field were also horizontal, but were only 0.1 mm. wide. They were resolved by the lens, and may have been resolved by the dog's eye, but being only 1-39 as wide as those on the positive field, an animal capable of distinguishing them as such should have had no difficulty in discriminating between them and the coarser system.

I introduced the dog to this problem 22 September 1915, using the general method already described. The mean brightness of both fields was 6.2 candles per square meter—a comfortable reading condition for the light adapted human eye. The intensity of the electric shock administered for incorrect responses was the same as that used in the immediately preceding experiment, in which it had proved effective and not greatly disturbing. The results of this experiment are shown in table 2. They show that the animal did not discriminate and did not improve in 500 trials. Since this dog was already trained to react in the box, and since he had learned readily to discriminate between other purely visual stimuli, I regard the evidence as conclusive that the dog does not distinguish relatively gross detail in visual objects, and that the deficiency is retinal.

[13] I wish to thank Dr. A. G. Worthing and Dr. W. Weniger for making this determination for me.

TABLE 2

RECORD OF DOG 1

Discrimination between plain and striate fields
Width of each stripe on positive field: 3.902 mm.
Width of each stripe on negative field: 0.104 mm.
Mean brightness of both fields: 6.2 candles per sq. meter
(Each test-object mounted in principal focus of lens, 399 mm. from nodal point)

Date	Number of trials given	Number of correct responses		Average percentage correct responses	Remarks
Sept. 22	20	12			
" 23	20	14			
" 24	20	11			
" 25	20	12			
" 26	20	12	1st 100 trials	61±3.4	
Sept. 27	20	11			
" 28	20	13			
" 29	20	10			
" 30	20	13			
Oct. 1	20	11	2d 100 trials	58±5.4	
Oct. 7	20	11			Not worked since Oct. 1
" 8	20	10			
" 9	20	12			
" 10	20	15			
" 11	20	10	3d 100 trials	58±7.6	
Oct. 12	20	10			
" 13	20	11			
" 14	20	9			
" 15	20	7			
" 16	20	13	4th 100 trials	50±8.0	
" 17	20	11			
" 18	20	9			
" 19	20	10			
" 20	20	10			
" 21	20	9	5th 100 trials	49±3.2	
Total. . .	500	276		55±6.6	

CONCLUSION

Throughout the theories of the most important writers on natural selection and sexual selection it is usually assumed either expressly or implicitly that animals are visually sensitive to certain patterns or markings of the plumage or hair of their own kind, as well as of their natural prey. Theories of protective and warning coloration and marking are built on such an assump-

tion. I hope at some later time to attempt an analysis of some of these theories with reference to this question. In so far as such assumptions are made to apply to animals the structure and function of whose eyes are typified by the dog, I am convinced that the foregoing experiments present at least presumptive evidence to the contrary.

If the dog's eye is not adapted to detail-vision, and if even a 4 to 1 brightness-difference is ineffective, as was indicated by the control tests of 14 September to 19 September, we may seriously inquire what useful purpose his vision serves. Orbeli, Kalischer and Smith have seriously attacked the problem of color-vision. Orbeli[14] used the saliva-reflex method of Pavloff, and attempted conscientiously to control his stimuli. He reports negative results. Kalischer[15] used a food-training method with muscular responses as the criterion. He reports definitely positive results. However, he worked without attempting to exclude certain obvious secondary stimuli, and his own report suggests that it was the latter which were actually effective. Smith's[16] use of colored papers for stimuli is open to fatal criticism, since they reflect a considerable amount of light of all wave-lengths, and since we know nothing as yet of the relative stimulating value of the different wave-lengths for the dog. It is not improbable that the range of effective wave-lengths is comparatively short for the dog, as it evidently is for rodents.[17] Smith seems to have used great care in the training-procedure, and is inclined to draw a positive conclusion from the results. I cannot see that the latter is warranted by the number of trials given and the percentage of correct responses obtained. Regarding the above and other tests of color-vision, it seems well to remark that all of them have been made only with test-fields of large area. In nature, different colors are usually presented as parts of patterns. This is especially true of the markings of plumage and hair. Proof of the existence of sensitivity to dif-

[14] Orbeli, L. A. Réflexes conditionnels du côte de l'oeil chez le chien. *Archives des sciences biologiques* (St. Petersburg), 1909.

[15] Kalischer, O. Weitere Mitteilung über die Ergebnisse der Dressur als physiologischer Untersuchungsmethode auf den Gebieten des Gehör-, Geruchs- und Farbensinns. *Arch. f. Physiol.*, 1909.

[16] Smith, E. M. Some observations concerning color-vision in dogs. *British Journal of Psychology*, vol. 5, 1912-13, pp. 119 ff.

[17] Watson, John B. and Watson, Mary I. A study of the responses of rodents to monochromatic light. This journal, vol. 3, 1913, pp. 1 ff.

ference in wave-length does not necessarily indicate that its possession is useful to the animal, unless there is evidence that his eye will "resolve" the patterns. Leaving the question of color-vision open, it should be remarked that the dog's retina seems well adapted to sensitivity to time-rate of change in intensity. In uncontrolled behavior all the normal dogs with which I have worked attended instantly to moving objects. I have often seen dogs chase the moving shadow of a cloud across the field, and bark at it vigorously. Sensitivity to rate of flicker, of various kinds and at various intensities, in lower mammals, constitutes a problem of great interest and importance. There is good ground for suspecting that such visual sensitivity is the most useful one which the lower mammals possess.

I wish to take this opportunity to acknowledge my indebtedness to Dr. P. W. Cobb for the work of examining the eyes of these animals; also to him and to Professors S. O. Mast and Harvey Carr for criticism which affected the direction and extent of the work. Finally, I should like to thank Mr. Arthur Lawrence, the owner of dog 1, for his generosity in permitting me to keep the animal for several months. It might have been quite difficult to find another dog with emmetropic eyes.

SUMMARY

In an earlier experiment normal dogs showed a surprising lack of superiority over blind dogs in learning to make complicated adjustments. A normal dog gave evidence that he did not depend on vision in making many of his ordinary responses in the field.

In another earlier experiment a 4 to 1 difference in luminous intensity, presented in addition to the difference in outline, enabled a dog to discriminate between a circle and its equivalent square. When the stimuli were equated in luminous intensity. discrimination ceased, and was not reestablished in 600 trials. The factor of refractive aberration was not determined.

In the present work, two chickens and one monkey learned in 300 to 400 trials to distinguish a striate field from a plain field equal to the former in area, outline, color and mean brightness. A dog with two emmetropic eyes failed to learn the problem in over 1,000 trials, although the striae on the positive field were made nearly six times as large for him as for the other animals.

The same animal was later trained in a short time to discriminate between two visual objects. During the training period the stimuli differed in area, pattern and luminous intensity, but only the latter difference was effective. When in a control test it was eliminated, and a 1 to 4 difference in mean brightness was presented with a 4 to 1 difference in area, the animal ceased to discriminate and did not learn to discriminate on the new basis. In this experiment and the one preceding reliance was placed on the animal's (assumed) ability to accommodate, and obtain a clear retinal image. The validity of the assumption could not be established on empirical evidence.

The same animal, continued in training by the same method, was now presented with a field covered with an extremely coarse pattern, to be discriminated from a uniform field of the same area, form and mean brightness. The conditions of the experiment insured the formation of a sharp image of the test-fields on the animal's unaccommodated eye. He failed to learn the problem or to make any improvement in 500 trials.

The cumulative evidence yielded by the above experiments indicates that the dog is very deficient in detail-vision, and that the immediate cause is the relative insensitivity of his retina to differences of distribution of brightnesses over it.

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A STUDY OF THE BEHAVIOR OF THE WHITE RAT BY THE MULTIPLE CHOICE METHOD

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INTRODUCTION

The multiple choice method of studying ideational and allied forms of behavior has already been described in connection with reports of results.[1] It consists essentially in presenting to a subject of any type, age, or condition a problem "which may be solved by the perception of a certain constant relation or group of relations within the reaction-mechanisms." For instance the subject may be required to operate the right-hand mechanism or the second from the left in a group of mechanisms varying in number from two to nine.

In this way the same *problem* can be presented to widely varied organisms, it being necessary merely to adapt the form of reaction mechanism to the species of animal. For human subjects a simple keyboard suffices,—the sounding of a buzzer as indication of a correct choice proving ample incentive to effort. With crows, pigs, ring-doves, rats and monkeys a series of similar boxes, each with an entrance and an exit door, has been employed, with confinement as punishment for incorrect choices and food as reward for correct choices. The value of this method from the comparative standpoint is obvious.

SUBJECTS

Three outbred and two inbred albino rats were used in the experiments. All were born in the Harvard Psychological Lab-

[1] Yerkes, Robert M. The study of human behavior. *Science*, 1914, **39**, 625-633.

Coburn, Charles A. and Yerkes, Robert M. A study of the behavior of the crow, *Corvus Americanus* Aud., by the multiple-choice method. *Journal of Animal Behavior*, 1915, **5**, 75-114.

Yerkes, Robert M. and Coburn, Charles A. A study of the behavior of the pig, *Sus scrofa*, by the multiple-choice method. *Journal of Animal Behavior*, 1915, **5**, 185-225.

Yerkes, Robert M. The mental life of monkeys and apes: a study of ideational behavior. *Behavior Monographs*, 1916. **3**, whole number 12.

oratory. Outbred females A and B and male D, all of the same litter, were born February 11, 1915, and were about five months old when they were first used, early in July. Inbred male J was born March 1, and began work early in August when five months of age. Inbred female C from another line was younger than the others, being born March 27 and beginning work when about three months of age.

These five subjects were selected from nine rats which were given preliminary training. They proved readier in forming the food-association and in getting accustomed to the apparatus than the other four, and it therefore seemed possible to bring them to a more uniform state of preparation prior to the actual experiments.

There were, however, very noticeable individual differences from the outset. A was rather timid, entering the compartments cautiously and with hesitation. D worked rather slowly and appeared in poor health from the start. B and C were extremely active and energetic, choosing successive doors with great rapidity and running to the food-dish at full speed.

The rats were not paired, but two or three of the same sex were caged together.

APPARATUS

The experiments were performed in a well lighted attic room at the writer's home in Haverhill, Massachusetts. A ground plan of the apparatus is shown in figure 1. It consisted of nine similar compartments, C, C, etc. with a door at each end,—the front door giving access to the reaction-chamber R and the rear door to the back alley A. The compartments were placed equidistant from the door of the entrance box E, along the arc of a quadrant of a circle.

The various doors, of sheet brass, were arranged to slide vertically and were operated from the experimenter's table by weighted strings passing through screw eyes above the doors. Those doors leading from the reaction-chamber into the nine compartments were arranged to remain 3-16 of an inch from the floor when closed, to avoid pinching the animal's tail. The entire apparatus was covered with wire netting and the floor was sprinkled with a light layer of sawdust.

From the reaction chamber the animal could enter one of the nine compartments, pass into the back alley, thence to the side

alley and the food-dish F. To facilitate its re-entrance into E, a light wooden door D was hinged to a frame sliding along the wall of the side alley S. Pulling a string caused this door to swing across the alley and then slide along in a transverse position toward the entrance box. This cut off the animal's retreat and, if necessary, pushed it into the entrance box. Another string pulled this device back to its original position.

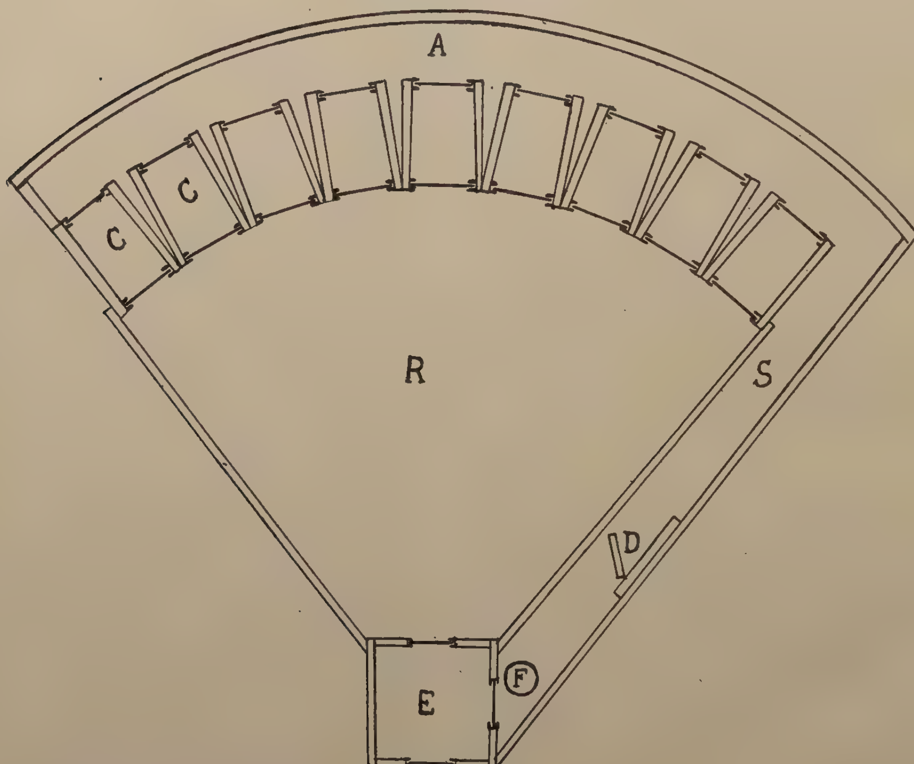

FIGURE 1. Ground plan of multiple-choice apparatus for rats. Scale 1:10 E, entrance-box; R, reaction-chamber; C, reaction-mechanisms; A, back alley; S, side alley; D, sliding door; F, food-dish. The doors (except D) moved vertically and were operated by weighted cords through screw-eyes not shown in the figure.

The interior dimensions of the nine compartments were: width 3 in., length 8 in., depth 4 in. Each front door was 24 in. from the door of the entrance box E. The alleys were 4 in. wide, the entrance box 6 x 6 in. and the entire apparatus 4 in. deep.

The apparatus rested on the floor on the side of the room opposite the only window, with the entrance box nearest the window and the front doors of the compartments directed toward the window. The experimenter sat about 10 feet distant behind a table near the window. A large mirror, hung at an angle of 45 degrees from the wall above the apparatus, illuminated it fairly uniformly and enabled the experimenter to observe the animal in positions that could not be seen directly.

PROBLEMS AND GENERAL METHOD

The first two of the standard problems[2] were presented to the various subjects,—viz. the selection of the first mechanism on the right and the selection of the second mechanism from the left. Below are given the ten settings of the doors which were presented in succession together with the number of the given setting in the series, the number of doors open and the number of the correct door. The doors were numbered from right to left as viewed by the subject.

Problem 1. First mechanism at the right end of the group

Settings	Doors open	No. of doors open	No. of right door
1	**1**.2.3	3	1
2	**8**.9	2	8
3	**3**.4.5.6.7	5	3
4	**7**.8.9	3	7
5	**2**.3.4.5.6	5	2
6	**6**.7.8	3	6
7	**5**.6.7	3	5
8	**4**.5.6.7.8	5	4
9	**7**.8.9	3	7
10	**1**.2.3	3	1
		Total 35	

Problem 2. Second mechanism from the left end of the group

Settings	Doors open	No. of doors open	No. of correct door
1	7.**8**.9	3	8
2	1.2.**3**.4	4	3
3	2.3.4.5.**6**.7	6	6
4	1.2.3.4.**5**.6	6	5
5	4.5.6.**7**.8	5	7
6	1.**2**.3	3	2
7	2.3.**4**.5	4	4
8	1.2.3.4.5.6.7.**8**.9	9	8
9	1.2.**3**.4	4	3
10	3.4.5.6.**7**.8	6	7
		Total 50	

[2] *Cf.* footnote 1.

In most cases the rats were given the ten settings in order in a single series of experiments. In a few of the earlier series it was not feasible to give ten trials in immediate succession.

Both punishment and reward were used as incentives. The punishment consisted of confinement in a compartment after an incorrect choice for 5 (in some cases 10) seconds. The reward consisted of food,—cold boiled potato or green corn proving most satisfactory. The rats were given all the food they wished during the afternoon and evening, but always fasted from 10 p. m. until the middle of the next forenoon when the experimental observations were usually made. If trials were made in the afternoon also, no food was given in the interim.

EXPERIMENTAL PROCEDURE

The usual procedure in a series was as follows. Sufficient food for 10 trials was placed in small bits in the food-dish. The rat was put into the entrance box through the rear door. The experimenter then took his seat at the table ten feet distant and remained there during the entire series. The proper entrance doors of the compartments were raised for the first trial, e. g., in Problem 1 doors 1, 2 and 3 were opened and all the others closed. The door leading from E into the reaction-chamber was then raised and the behavior of the rat was recorded in symbols from its entrance into the chamber until its arrival at the food.

If the animal entered the wrong compartment the door behind it was closed for 5 seconds,—the experimenter counting the tics of the stop-watch. The rat was then allowed to retreat from the compartment and make another choice. This procedure was repeated until the rat entered the correct compartment, whereupon the door behind it was closed and the exit-door opened immediately. The rat then ran along the alley to the food-dish. The experimenter immediately pulled a string closing the door across the alley behind the animal. After a few seconds the door from the alley to the entrance box was raised, and the door behind the rat pulled along until it drove or pushed him into the entrance box. Most of the rats, however, soon acquired the habit of picking up a bit of food, waiting until the door in front of them opened and then going into the entrance box to eat at their leisure. Meanwhile the doors were set for the next

trial and the rat, when ready, was admitted again into the reaction-chamber for another trial. The time from the entrance into the reaction-chamber until the arrival at the food was measured with a stop-watch.

PRELIMINARY TRAINING

The rats were placed in the apparatus in groups of two or three with all the doors open and with food in the food-dish. They were left there for three hours. This procedure was repeated for three days.

Then with all the entrance doors of the nine compartments open, a rat was admitted to the reaction-chamber. When he entered *any* compartment the door was closed behind him and the exit door immediately raised and he found his way to the food. He was allowed to eat for a few seconds, then pushed into the entrance box and readmitted to the reaction-chamber with all the entrance doors open. This was repeated for half an hour. Such preliminary training was continued until the animal made ten choices in half an hour. This necessitated in most cases only two or three series, of half hour's length, a day apart.

The following day the rat was given the opportunity to secure success at each of the nine boxes. No. 1 was the only door open on the first trial, No. 2 on the second, etc. The next day this was reversed, No. 9 being the only door open on the first trial, No. 8 on the second, etc. The rats by this time had the food-association well formed and appeared to be in a state of uniform preparation for the regular experiments.

RESULTS OF EXPERIMENTS

As it is essential to present the data for each trial in the series of experiments, tables I, II, III, IV, V, and VI have been constructed after the following manner. At the head of each table stand the several settings, the letter S serving as an abbreviation for setting and the number following it designating the place of the setting in the series. Immediately under the number of the setting appear the numbers of the doors open, with the one to be chosen (correct one) in bold face type. The column at the left gives the date. The second column gives the number of the various trials in the whole series. Following these num-

bers are the results for the trials indicated,—the figures denoting the numbers of the boxes entered in the order of entrance. The last five columns give the number of correct and incorrect first choices in a given series of ten, the total number of right and wrong first choices on a given day and the daily ratio of right to wrong. At the bottom of the tables for problem 1 appear the results in a check series of ten trials with ten new settings. For example, referring to table I, we see that rat A entered compartment No. 3 on the first trial and after punishment by confinement entered No. 1 which was correct; in the 56th trial she entered No. 8 three times in succession, being punished for each entrance and then entered No. 6 the correct one. The time of the trials, although recorded as a matter of routine is not included in the results.

The tables enable one to obtain quickly information concerning the forms of response and the changes therein during the course of the experiment. Further comment will be made in the following section.

DISCUSSION OF RESULTS

Problem 1, which consisted in the selection of the reaction mechanism on the subject's right, proved soluble for the four rats, i. e., they were able to make correct first choices in ten consecutive trials on the ten settings.

Outbred female A was successful after 170 trials and her brother D after 200. Inbred male J, of about the same age, solved the problem in 170 trials, while the younger inbred female C required 350.

In this problem the total number of doors open in the ten settings is 35. Of these 10 were of course correct. Hence the probability of a correct first choice in any trial is 10-35 and the probable ratio of correct to incorrect first choices in any series apart from experience is 1 to 2.5. The tables show that D and J started with a ratio for the first day of 1 to 9 which is much less efficient than was to be expected, while A and C were more efficient than expectation with ratios of 1 to .66. These differences were perhaps due to a tendency to go toward the right on the part of A and C, while with D the opposite tendency was manifest throughout.

After solution of the problem each animal was given 10 trials

TABLE I
RESULTS FOR RAT A, OUTBRED FEMALE, IN PROBLEM 1

Date	No. of trials	S. 1 **1**.2.3	S. 2 8.9	S. 3 **3**.4.5.6.7	S. 4 **7**.8.9	S. 5 2.3.4.5.6	S. 6 **6**.7.8	S. 7 **5**.6.7	S. 8 **4**.5.6.7.8	S. 9 **7**.8.9	S. 10 **1**.2.3	R	W	R	W	Ratio of R to W
July 8	1– 10	3.1	8	3	8.7	6.2	6	5	4	7	2.2.3.1	6	4	6	4	1:0.66
9	11– 20	3.2.1	8	4.7.3	7	5.2	7.6	6.7.5	4	7	3.3.1	4	6			
"	21– 30	1	8	3	7	5.3.6.2	6	5	4	7	1	9	1	13	7	1:0.54
10	31– 40	2.3.1	8	4.7.3	7	4.6.2	6	5	4	7	3.3.3.2.1	6	4	6	4	1:0.66
12	41– 50	2.1	8	3	8.9.7	2	8.6	6.5	8.4	7	1	5	5	5	5	1:1.00
13	51– 60	2.1	8	6.3	9.7	6.2	8.8.8.6	5	6.7.4	7	3.1	3	7	3	7	1:2.33
14	61– 70	1	8	5.3	8.7	2	6	5	4	9.7	3.1	6	4			
"	71– 80	2.3.2.1	9.8	4.3	7	2	8.6	5	4	7	3.1	5	5	11	9	1:0.81
15	81– 90	3.1	8	3	7	2	8.6	5	4	9.7	1	7	3			
"	91–100	1	8	5.3	8.7	2	6	6.5	8.5.4	7	1	6	4	13	7	1:0.54
16	101–110	1	8	3	7	5.2	6	5	5.4	7	3.2.1	7	3			
"	111–120	2.1	8	3	7	3.2	6	5	4	7	3.1	7	3	14	6	1:0.43
17	121–130	2.1	8	6.4.3	7	4.2	6	6.5	4	7	3.1	5	5	5	5	1:1.00
18	131–140	1	8	3	7	5.2	6	5	5.7.4	7	1	8	2	8	2	1:0.25
19	141–150	2.1	8	3	7	2	6	5	5.4	7	3.1	7	3			
"	151–160	3.1	8	7.3	9.7	2	8.6	5	4	7	1	6	4	13	7	1:0.54
20	161–170	1	8	3	7	2	6	5	4	7	1	10	0	10	0	1:0.00
		2.3.**4**	**6**.7.8.9	3.4.**5**	**4**.5.6.7.8.9	**6**.7.8.9	**1**.2.3.4.5	**2**.3.4.5 6.7.8	**3**.4.5.6.7.8	**5**.6.7	**1**.2.3.4.5 6.7.8.9					
20	1– 10	2	6	3	9.4	6	1	2	3	5	1	9	1	9	1	1:0.11
Retention Sept. 9		1	8	3	7	2	8.6	5	4	9.9.7	1	8	2			

TABLE II
RESULTS FOR RAT D, OUTBRED MALE, IN PROBLEM 1

Date	No. of trials	S. 1 1.2.3	S. 2 8.9	S. 3 3.4.5.6.7	S. 4 7.8.9	S. 5 2.3.4.5.6	S. 6 6.7.8	S. 7 5.6.7	S. 8 4.5.6.7.8	S. 9 7.8.9	S. 10 1.2.3	R	W	R	W	Ratio of R to W
July 4	1– 10	3.2.1	9.8	4.6.3	9.9.8.7	6.5.3.3.3.2	7.7.7.6	6.5	6.5.4	7	3.2.1	1	9	1	9	1:9.00
6	11– 20	1	9.9.8	4.3	9.7	5.2	6	6.5	8.7.5.4	7	2.1	3	7	3	7	1:2.33
7	21– 30	3.1	9.8	6.3	7	6.5.4.3.2	7.6	7.5	7.5.4	7	3.2.1	2	8	2	8	1:4.00
8	31– 40	3.1	8	3	8.7	2	8.6	7.6.5	8.7.5.4	9.7	3.2.1	3	7	3	7	1:2.33
9	41– 50	3.1	9.8	7.6.5.4.3	9.7	5.3.2	8.6	5	7.6.4	9.7	3.2.1	1	9	1	9	1:9.00
12	51– 60	3.1	9.8	7.4.3	9.8.7	6.4.2	7.6	7.5	4	9.7	3.1	1	9	1	9	1:9.00
13	61– 70	3.1	8	7.4.3	7	6.4.2	6	7.5	4	9.7	3.1	4	6	4	6	1:1.50
14	71– 80	3.1	9.8	3	9.7	5.3.2	8.6	5	4	8.7	3.1	3	7			
"	81– 90	3.1	9.8	3	7	3.2	8.6	6.5	5.4	7	3.1	3	7	6	14	1:2.33
15	91–100	3.1	8	3	8.7	2	6	6.5	5.4	8.7	3.1	4	6			
"	101–110	3.1	8	4.3	8.7	3.2	6	7.5	4	7	2.1	4	6	8	12	1:1.50
16	111–120	3.2.1	9.8	4.3	9.7	4.2	6	6.5	4	7	3.1	3	7			
"	121–130	3.1	8	3	8.7	3.2	6	7.5	8.4	9.7	3.1	3	7	6	14	1:2.33
17	131–140	2.1	9.8	3	8.7	2	6	5	4	8.7	1	6	4	6	4	1:0.66
18	141–150	1	8	3	8.7	2	6	5	8.7.6.4	7	1	8	2	8	2	1:0.25
19	151–160	1	8	3	7	2	6	6.5	4	7	1	9	1			
"	161–170	1	8	3	9.8.7	2	6	5	4	8.7	1	8	2	17	3	1:0.17
20	171–180	1	8	4.3	9.7	2	6	6.5	4	8.7	1	6	4			
"	181–190	1	8	3	8.7	2	6	5	4	7	3.2.1	8	2	14	6	1:0.43
21	191–200	1	8	3	7	2	6	5	4	7	1	10	0	10	0	1:0.00
		2.3.4	6.7.8.9	3.4.5	4.5.6.7.8.9	6.7.8.9	1.2.3.4.5	2.3.4.5 6.7.8	3.4.5.6.7.8	5.6.7	1.2.3.4.5 6.7.8.9					
21	1– 10	2	6	3	4	6	1	2	6.4.3	5	1	9	1	9	1	1:0.11

TABLE III
RESULTS FOR RAT J, INBRED MALE, IN PROBLEM 1

Date	No. of trials	S. 1 **1.2.3**	S. 2 **8.9**	S. 3 **3.4.5.6.7**	S. 4 **7.8.9**	S. 5 **2.3.4.5.6**	S. 6 **6.7.8**	S. 7 **5.6.7**	S. 8 **4.5.6.7.8**	S. 9 **7.8.9**	S. 10 **1.2.3**	R	W	R	W	Ratio of R to W
Aug. 10	1– 10	3.2.1	8	7.6.5.3	8.9.8.7	6.3.2	8.6	7.5	8.6.4	9.7	3.2.1	1	9	1	9	1:9.00
11	11– 20	3.2.1	8	7.6.3	8.7	6.6.2	7.8.7.6	7.5	5.4	8.7	3.1	1	9			
"	21– 30	2.3.1	8	7.7.5.3	8.7	6.4.2	8.6	5	8.6.4	7	1	4	6	5	15	1:3.00
12	31– 40	2.3.2.1	8	3	8.7	2	7.6	5	4	7	1	7	3			
"	41– 50	2.3.2.1	8	3	7	4.3.2	8.7.6	5	4	7	2.3.2.1	6	4	13	7	1:0.54
13	51– 60	3.2.1	8	7.4.3	7	2	6	5	4	7	1	8	2			
"	61– 70	2.1	8	4.3	7	5.3.2	6	5	5.4	7	3.2.1	5	5	13	7	1:0.54
14	71– 80	1	8	3	7	4.3.2	6	6.5	6.8.4	7	1	7	3	7	3	1:0.43
16	81– 90	1	8	4.7.3	8.7	2	6	6.5	4	7	1	7	3	7	3	1:0.43
17	91–100	1	8	4.3	7	3.2	6	5	4	7	3.2.1	7	3			
"	101–110	2.1	8	4.3	7	4.2	6	6.5	4	7	1	6	4	13	7	1:0.54
18	111–120	3.1	8	4.3	7	4.3.2	7.8.6	5	4	7	2.1	5	5	5	5	1:1.00
19	121–130	1	8	4.3	7	3.2	6	6.7.5	4	7	1	7	3	7	3	1:0.43
20	131–140	1	8	3	7	3.6.2	6	6.5	5.4	7	1	7	3			
"	141–150	2.1	8	4.3	7	3.2	7.6	5	4	7	1	6	4			
"	151–160	1	8	4.3	7	3.2	6	5	4	7	2.1	7	3			
"	161–170	1	8	3	7	2	6	5	4	7	1	10	0	30	10	1:0.33
		2.3.4	**6.7.8.9**	**3.4.5**	**4.5.6.7.8.9**	**6.7.8.9**	**1.2.3.4.5**	**2.3.4.5** 6.7.8	**3.4.5.6.7.8**	**5.6.7**	**1.2.3.4.5** 6.7.8.9					
20	1– 10	2	6	3	6.4	6	1	2	3	5	9.8.5.3.2.1	8	2	8	2	1:0.25

TABLE IV

RESULTS FOR RAT C, INBRED FEMALE, IN PROBLEM 1

Date	No. of trials	S. 1 1.2.3	S. 2 8.9	S. 3 3.4.5.6.7	S. 4 7.8.9	S. 5 2.3.4.5.6	S. 6 6.7.8	S. 7 5.6.7	S. 8 4.5.6.7.8	S. 9 7.8.9	S. 10 1.2.3	R	W	R	W	Ratio of R to W
June																
27	1– 10	3.2.1	8	3	7	4.2	6	7.5	4	7	3.1	6	4	6	4	1:0.66
28	11– 20	3.3.1	8	3	7	4.4.2	6	7.5	4	7	3.1	6	4	6	4	1:0.66
29	21– 30	2.1	8	5.3	7	6.2	6	5	6.8.4	9.7	3.1	4	6			
"	31– 40	2.1	8	3	7	5.2	7.6	5	4	7	3.2.1	6	4	10	10	1:1.00
30	41– 50	3.2.1	8	3	7	3.6.6.2	8.6	7.5	5.8.5.4	7	2.1	4	6	4	6	1:1.50
July																
1	51– 60	2.1	8	4.3	8.7	3.2	6	7.6.5	6.8.4	9.7	1	3	7			
"	61– 70	3.2.1	9.8	3	7	3.2	6	5	5.4	7	2.1	5	5	8	12	1:1.50
2	71– 80	2.1	8	3	7	4.3.2	8.6	5	4	9.7	3.3.1	5	5	5	5	1:1.00
3	81– 90	3.2.1	8	4.7.3	7	6.3.2	7.6	6.5	7.4	7	3.2.2.1	3	7			
"	91–100	3.2.1	8	7.6.5.3	7	2	6	5	4	7	1	8	2	11	9	1:0.81
4	101–110	3.2.1	8	7.3	7	4.3.2	6	7.5	5.4	7	3.2.1	4	6	4	6	1:1.50
6	111–120	2.1	8	7.3	7	4.3.2	7.6	6.5	5.4	7	1	4	6	4	6	1:1.50
7	121–130	3.1	8	6.3	7	3.2	7.6	7.5	4	9.7	2.1	3	7			
"	131–140	2.1	8	7.3	7	3.2	6	7.5	5.4	7	3.2.1	4	6	7	13	1:1.85
8	141–150	2.1	8	7.3	7	2	6	5	5.4	7	3.2.1	6	4			
"	151–160	3.2.1	8	3	7	5.3.2	6	5	7.4	7	2.1	6	4	12	8	1:0.66
9	161–170	3.2.1	8	3	7	3.2	6	5	5.4	7	2.1	6	4			
"	171–180	2.1	8	7.6.5.4.3	8.9.7	4.3.2	6	6.5	6.7.8.5.4	8.7	3.2.1	2	8	8	12	1:1.50
12	181–190	1	8	6.3	7	3.2	8.7.6	6.5	7.8.5.4	7	1	5	5	5	5	1:1.00
13	191–200	2.1	8	4.3	7	2	7.6	5	4	7	2.1	6	4	6	4	1:0.66
14	201–210	1	8	3	7	3.2	6	6.5	6.4	7	1	7	3			
"	211–220	1	8	3	7	2	7.6	6.5	4	7	1	8	2	15	5	1:0.33
15	221–230	2.1	8	3	7	2	7.6	5	4	7	2.1	7	3			
"	231–240	1	8	3	7	2	6	6.5	4	7	1	9	1	16	4	1:0.25
16	241–250	1	8	3	7	2	6	6.5	4	7	2.1	8	2			
"	251–260	1	8	3	8.7	2	6	6.5	8.4	7	1	7	3	15	5	1:.033
17	261–270	2.1	8	3	7	2	6	7.5	8.5.7.4	7	1	7	3	7	3	1:.043
18	271–280	1	8	3	7	6.3.2	6	6.5	6.4	7	2.3.1	6	4	6	4	1:0.66
19	281–290	1	8	3	7	2	6	7.5	4	7	1	9	1			
"	291–300	1	8	3	7	2	7.6	5	4	7	1	9	1			
"	301–310	1	8	3	7	2	6	5	5.4	8.9.9.7	1	8	2	26	4	1:0.15
20	311–320	1	8	3	7	3.2	6	5	4	7	1	9	1			
"	321–330	1	8	3	7	5.4.2	6	5	4	7	1	9	1	18	2	1:0.11
21	331–340	1	8	3	7	2	6	7.5	4	7	1	9	1			
"	341–350	1	8	3	7	2	6	5	4	7	1	10	0	19	1	1:0.05
		2.3.4	6.7.8.9	3.4.5	4.5.6.7.8	6.7.8.9	1.2.3.4.5	2.3.4.5 6.7.8	3.4.5.6.7.8	5.6.7	1.2.3.4.5 6.7.8.9					
22	1– 10	2	6	3	4	6	1	2	3	5	1	10	0	10	0	1:0.00

on 10 new settings to check the possibility of memorizing the particular settings rather than actually solving the problem. One of the rats did the check series perfectly, two others with only one mistake, and the other with two mistakes. It is evident that all formed the habit of selecting the compartment at the extreme right.

A number of interesting individual tendencies were manifested in the course of the experiment. A's method of reaction was usually as follows: passing down the right wall of the reaction-chamber to compartment No. 1, she turned leftward and followed along close to the compartments until she reached the first open door. In many instances she turned from the right wall before reaching compartment No. 1, with the result that she entered a door too far to the left. This factor was of course more operative with settings comprising doors at the right end. It is evident from table I that settings 1, 3, 5 and 10 yield a larger number of incorrect first choices than do the others. With settings farther toward the left the first approach to the doors brought the subject more often in front of a closed door and hence the first open one encountered was correct. On Sept. 9, over seven weeks after the discontinuance of A's training, she was given 10 trials with the original settings and made 8 correct choices out of 10. Evidently the habit was still strong.

D manifested a tendency entirely different from that of A. He ran along the left wall of the reaction-chamber and across in front of the open doors until he reached a closed one, whereupon he turned back into the last open one. This turning back appeared to be caused by the touch of the vibrissae on the closed door rather than by the sight of it. The turning was always in the same direction,—leftward or toward the doors. D experienced more difficulty than the other rats with setting No. 2, i. e., doors 8 and 9. Going down the left wall he often entered compartment No. 9, whereas he normally turned at that point. As he did poorly also on the other settings involving No. 9, it would appear that he was reacting by tactual rather than visual criteria,—habitually going along the wall until he encountered an obstacle and then turning across, etc. The directness with which No. 9 was entered in contrast with any other door was noticeable. A month after the training ended, although sick and able to move only slowly, he performed two trials correctly

on the first two settings, employing his customary method of reaction.

J manifested, like A, a tendency to go down the right wall of the reaction chamber to compartment No. 1 and then in front of the closed doors to the first open one. He was often, however, premature in turning to the left thus missing the first open door, and he often lost the latter part of his habit and passed several open doors without entering. As contrasted with A, he was less ready in recovery from mistakes. Both solved the problem in 170 trials, but whereas with A there were 17 trials in which more than one incorrect choice was made before the correct one, there were 31 such trials with J. It is to be remembered that J was inbred and A outbred.

C was extremely rapid in her motions, rushing toward the compartments the moment she was released from the entrance box. In her correct trials the total time from entrance-box, through the compartment and alleys to the food was frequently 5 seconds. She often ran along the back alley so rapidly that she slipped and fell at the turn into the side alley. This tendency to hasten was perhaps instrumental in her failure to solve the problem in less than 350 trials. She usually appeared to take her orientation from door No. 1, going thence leftward to the correct door. The settings comprising doors at the left proved easy by this method. The most noticeable thing about her behavior was the suddenness with which she sometimes became thus oriented. Frequently when pausing and looking in the wrong door, or smelling about in almost any part of the reaction-chamber she would suddenly dash to door No. 1 and then across into the correct one. It is possible that this is the same phenomenon mentioned by Watson,[3] where a trained rat, placed in a part of the maze other than the entrance, runs about at random and suddenly darts off correctly, having passed over a "kinaesthetic unit" which arouses a proper sequence of kinaesthetic impulses.

Problem 2, which is definable as the second mechanism from the left end of the group, proved insoluble for the two rats C and B in 800 and 900 trials respectively.

For the settings of this problem the total number of open doors is 50 with 10 of course correct. Hence the probability of

Watson, J. B. Behavior. New York, 1914, p. 218.

TABLE V

RESULTS FOR RAT C, INBRED FEMALE, IN PROBLEM 2

Date	No. of trials	S. 1 7.8.9	S. 2 1.2.3.4	S. 3 2.3.4.5.6.7	S. 4 1.2.3.4.5.6	S. 5 4.5.6.7.8	S. 6 1.2.3	S. 7 2.3.4.5	S. 8 1.2.3.4.5 6.7.8.9	S. 9 1.2.3.4	S. 10 3.4.5.6.7.8	R	W	R	W	Ratio of R to W
July 26	1– 10	7.7.7.7. 9.7.8	3	2.2.2.7.6	3.2.1.6 1.4.5	4.4.4.6.7	1.1.2	2.4	4.6.7.8	3	3.3.4.5 3.6.7	2	8	2	8	1: 4.00
27	11– 20	7.7.7.9.7.8	4.3	5.2.2.4.6	5	4.6.7	1.3.1.1.3 3.3.3.2	2.4	1.3.4.5 6.7.8	1.3	3.4.5.7	1	9			
"	21– 30	7.8	1.2.3	6	5	6.7	1.2	2.3.4	5.6.7.8	4.1.2.4 2.1.3	6.7	2	8	3	17	1: 5.66
28	31– 40	7.8	1.2.3	2.3.4.5.6	6.1.3.5	6.4.5.6.7	3.1.3.3.2	2.5.3.5.3 5.2.3.5.4	4.5.6.7.8	4.4.1.4.3	4.5.6.7	0	10			
"	41– 50	7.8	1.2.3	2.3.4.5.6	6.1.3.5	6.7	1.3.3.3.2	4	4.5.6.7.8	4.3	3.4.5.6.7	1	9	1	19	1:19.00
29	51– 60	7.8	4.1.3	4.5.6	3.2.4.1.6.3 1.6.2.3.4 3.2.1.6.5	5.6.7	3.2	4	5.6.7.8	4.3	4.5.7	1	9			
"	61– 70	7.8	3	7.3.4.5.6	1.3.4.5	4.5.6.7	3.3.2	2 3.4.	4.1.9.9.8	2.1.3	5.7	1	9			
"	71– 80	7.8	4.2.1.1.3	7.2.3.4.5.6	6.2.3.4.5	7	3.2	5.3.4	6.7.8	1.1.2.3	8.6.7	1	9			
"	81– 90	7.7.8	2.3	3.4.5.6	6.2.1.1 2.3.4.5	8.7	1.2	3.4	5.6.7.8	1.3	8.3.5.6.7	0	10	3	37	1:12.33
30	91–100	7.8	1.2.3	7.6	2.3.4.5	4.5.6.7	3.1.2	2.3.4	8	1.2.3	8.4.5.6.7	1	9			
"	101–110	8	1.2.3	7.2.4.5.6	1.2.3.4.5	8.7	3.2	2.3.4	7.8	1.2.3	8.4.5.6.7	1	9	2	18	1: 9.00
31	111–120	8	1.2.3	4.5.6	1.2.1.2 3.4.5	8.6.7	3.2	5.4	1.2.3.4.5.8	1.2.3	9.6.5.6.7	1	9	1	9	1: 9.00
Aug. 4	121–130	7.8	3	7.4.5.6	3.4.5	8.6.7	1.2	2.3.4	7.8	4.2.1.4 1.4.3	8.5.6.7	1	9			
"	131–140	8	3	3.4.2.3 4.5.6	6.1.2.3.4.5	8.5.6.7	3.2	5.4	7.8	4.3	3.8.4.5.6.7	2	8	3	17	1: 5.66
5	141–150	9.8	3	7.2.3.2 3.4.5.6	6.6.5	8.4.5.6.7	1.3.2	5.2.3.4	8	2.3	7	3	7			
"	151–160	9.7.8	4.3	2.3.4.5.6	2.3.4.5	7	1.2	4	7.8	4.3	7	3	7			
"	161–170	9.7.8	4.2.3	2.3.2.4.7 3.4.5.6	6.1.2.3.4.5	8.5.6.7	3.2	5.4	7.8	1.2.3	8.3.4.5.6.7	0	10			

TABLE V—*Continued*

RESULTS FOR RAT C, INBRED FEMALE, IN PROBLEM 2

Date	No. of trials	S. 1 7.8.9	S. 2 1.2.3.4	S. 3 2.3.4.5.6.7	S. 4 1.2.3.4.5.6	S. 5 4.5.6.7.8	S. 6 1.2.3	S. 7 2.3.4.5	S. 8 1.2.3.4.5 6.7.8.9	S. 9 1.2.3.4	S. 10 3.4.5.6.7.8	R	W	R	W	Ratio of R to W
Aug. "	171–180	8	4.2.1.2.3	7.7.6	4.3.2.1 6.4.5	8.8.6.7	3.2	5.3.4	8	4.2.3	8.4.5.6.7	2	8	8	32	1: 4.00
6	181–190	7.8	1.2.3	7.4.5.6	6.3.2.3.4.6 1.2.3.4.5	5.6.7	3.2	4	7.8	4.3	8.1.3.4 5.6.7	1	9	1	9	1:9.00
7	191–200	8	2.1.2.3	6	4.5	7	2	5.2.4	7.8	4.3	7	5	5			
"	201–210	7.8	4.3	7.7.2.3 4.5.6	6.2.3.4.5	7	1.3.2	5.4	7.8	2.1.4.2.3	8.7	1	9			
"	211–220	7.8	1.2.3	7.7.4.5.6	6.2.3.4.5	8.4.5.6.7	3.1.2	3.4	8	4.1.2.3	8.7	1	9	7	23	1: 3.28
9	221–230	8	1.3	4.5.7.7.6	6.5	8.4.4.4.7	2	3.4	8	1.3	5.8.7	3	7	3	7	1: 2.33
10	231–240	7.8	4.2.3	6	6.1.2.3.4.5	7	3.2	5.3.5.4	8	4.3	8.7	3	7	3	7	1: 2.33
11	241–250	7.8	3	4.2.3.4.5.6	6.1.2.3.4.5	8.6.7	1.3.2	4	8	2.4.1.2.3	8.7	3	7	3	7	1: 2.33
12	251–260	7.8	3	3.5.6	6.5	8.4.5.6.7	3.2	5.4	8	4.3	8.3.5.6.7	2	8	2	8	1: 4.00
13	261–270	7.8	3	4.3.2.7.5 4.3.2.7.6	6.1.3.4.5	8.4.5.6.7	3.2	5.4	8	2.1.2.3	8.8.1.5 6.7	2	8	2	8	1: 4.00
14	271–280	7.8	4.3	7.6	1.3.2.1 6.3.4.5	7	3.2	5.4	8	3	8.7	3	7	3	7	1: 2.33
16	281–290	7.8	3	7.4.3.7.6	5	8.5.6.7	3.2	5.2.3.4	8	2.1.3	8.7	3	7	3	7	1: 2.33
17	291–300	7.8	4.3	7.2.3.7 4.5.6	5	8.7	3.2	5.2.5.4	8	4.3	8.7	2	8			
"	301–310	8	4.3	7.2.3.4 3.4.5.6	6.3.2.3.4.5	8.5.4.6.7	3.1.2	5.4	8	4.3	8.6.5.4 3.5.6.7	2	8	4	16	1: 4.00
18	311–320	7.8	4.3	2.3.5.4.7.6	6.3.4.3 2.4.5	8.7	1.2	4	8	3	4.3.6.7	3	7	3	7	1: 2.33
20	321–330	7.8	2.4.1.2.3	7.5.6	6.3.4.5	8.7	3.2	3.5.4	9.8	1.2.3	7	1	9			
"	331–340	7.8	2.3	4.5.6	6.5	8.7	3.2	4	5.4.3.2.1.3 4.5.6.7.8	1.2.3	8.7	1	9	2	18	1: 9.00
21	341–350	7.8	3	7.2.4.5.4.6	6.2.3.2 1.4.5	8.7	3.2	3.4	8	2.1.4.3	7	3	7	3	7	1: 2.33
23	351–360	7.8	3	6	3.2.4.3 2.1.5	8.7	3.1.3.2	5.4	8	4.3	8.7	3	7			

"	361–370	7.8	3	2.3.4.5.6	4.3.2.3.4.5	8.7	3.2	5.4	8	2.2.1.4.3	8.7	2	8			
"	371–380	7.8	4.3	6	2.1.2.3.4.5	8.7	3.2	4	9.7.6.7.8	4.3	8.7	2	8	7	23	1: 3.28
24	381–390	7.8	4.3	6	5	8.7	3.2	5.4	3.2.1.8	3	7	4	6			
"	391–400	7.8	3	4.5.6	6.5	5.4.6.7	3.2	3.5.4	8	4.3	8.7	2	8	6	14	1: 2.33
25	401–410	8	4.3	7.6	2.1.3.4.5	8.7	3.2	5.4	7.6.5.4 3.2.9.8	1.3	8.7	1	9			
"	411–420	8	3	2.6	6.5	5.6.7	3.2	2.4	7.8	2.3	8.7	2	8			
"	421–430	7.8	4.3	7.6	6.5	7	3.2	4	9.8	4.3	8.6.5.4 3.8.7	2	8	5	25	1: 5.00
26	431–440	7.8	4.3	2.5.6	6.5	8.7	1.3.2	5.4	7.8	4.3	6.7	0	10			
"	441–450	7.8	4.3	2.5.6	3.2.3.4.5	8.7	3.3.2	4	8	3	8.7	3	7	3	17	1: 5.66
27	451–460	7.8	3	2.5.6	1.4.5	7	2	4	3.2.6.7.8	2.1.4.3	3.1.6.7	4	6			
"	461–470	7.8	4.3	7.6	5	8.7	3.2	5.4	3.2.1.8	4.3	8.7	1	9			
"	471–480	7.8	3	2.4.5.6	6.5	8.7	2	3.2.5.4	1.1.5.6.7.8	3	7	4	6			
"	481–490	8	3	7.6	3.2.3.4.5	7	2	2.3.4	8	1.4.3	8.7	5	5	14	26	1: 1.85
28	491–500	8	4.3	7.6	6.5	8.7	2	4	7.8	3	8.7	4	6	4	6	1: 1.50
30	501–510	7.8	2.4.3	6	6.4.3.5	7	1.2	3 2.4	8	4.3	8.7	3	7			
"	511–520	8	3	7.6	5	7	3.2	5.4	7.9.9.8	4.3	6.5.4.3.6.7	4	6	7	13	1: 1.85
31	521–530	7.8	2.4.3	7.6	3.2.6.5	8.7	2	5.4	9.7.6.5.4 3.2.1.4 5.6.7.8	1.4.3	8.7	1	9			
"	531–540	8	4.3	2.3.4.5.6	6.5	8.7	3.2	4	7.8	3	3.4.5.6.8.7	3	7			
"	541–550	8	3	7.6	6.5	4.8.7	1.3.2	3 5.4	8	2.4.3	7	4	6	8	22	1: 2.75
Sept. 1	551–560	8	3	7.6	6.5	5.4.8.7	3.2	1.4	5.4.8	4.3	5.4.3.6.8.7	2	8			
"	561–570	9.8	3	7.6	5	8.7	1.3.2	4	9.2.5.4.8	4.3	7	4	6	6	14	1: 2.33
2	571–580	8	2.1.4.3	7.6	3.2.1.4.5	8.7	3.2	4	7.6.5.4.3 2.1.6.7.8	3	7	4	6			
"	581–590	8	4.2.4.3	7.6	6.5	8.7	2	5.4	8	2.4.3	8.7	3	7			
"	591–600	8	3	7.6	5	8.7	3.1.2	5.4	8	3	8.7	5	5	12	18	1: 1.50
3	601–610	9.8	3	4.5.6	6.4.3.6.5	8.7	3.2	4	3.2.1.7.8	4.3	7	3	7			
"	611–620	8	4.3	7.6	6.5	6.8.7	3.3.2	5.4	7.8	3	7	3	7			
"	621–630	9.8	3	7.6	4.5	8 7	3.2	5.4	7.8	2.4.3	6.7	1	9	7	23	1: 3.28
4	631–640	8	3	7.6	1.5	7	3.2	5.4	7.9.5.4 6.7.8	3	8.7	4	6			
"	641–650	8	2.4.3	5.4.3.2 4.5.6	6.5	7	3.2	5.4	7.8	4.3	7	3	7			
"	651–660	9.8	3	5.7.6	2.4.5	8.6.5.4 7	1.3.1.2	5.4	7.6.5.4 3.2.5.8	3	5.8.3.7	2	8	9	21	1: 2.33

TABLE V—*Continued*

RESULTS FOR RAT C, INBRED FEMALE, IN PROBLEM 2

Date	No. of trials	S. 1 7.8.9	S. 2 1.2.3.4	S. 3 2.3.4.5.6.7	S. 4 1.2.3.4.5.6	S. 5 4.5.6.7.8	S. 6 1.2.3	S. 7 2.3.4.5	S. 8 1.2.3.4.5 6.7.8.9	S. 9 1.2.3.4	S. 10 3.4.5.6.7.8	R	W	R	W	Ratio of R to W
Sept. 5	661–670	8	4.3	7.6	6.5	7	3.2	5.4	8	4.3	8.7	3	7			
"	671–680	7.8	4.3	7.6	1.3.2.5	7	2	4	3.1.6.7.8	4.3	7	4	6			
"	681–690	7.9.8	4.2.1.3	7.6	6.5	7	1.3.1.2	5.3.2.5.4	8	4.3	8.7	2	8	9	21	1: 2.33
7.	691–700	8	3	7.5.2.4 3.7.6	5	4.7	3.2	5.4	6.8	4.3	8.4.3.7	3	7	3	7	1: 2.33
8	701–710	7.9.8	3	7.2.4.6	6.6.5	8.7	3.2	5.4	7.8	3	8.7	2	8			
"	711–720	7.9.8	4.3	6	1.2.6.5	7	3.2	4	8	4.3	8.7	4	6			
"	721–730	9.8	3	7.6	6.5	8.7	3.2	5.4	7.6.5.4 3.2.9.8	4.3	8.7	1	9			
"	731–740	8	3	7.6	4.3.2.4.5	8.7	2	3.2.5.4	7.8	2.1.4.3	8.7	3	7	10	30	1: 3.00
9	741–750	8	2.4.3	7.6	5	5.7	2	3.2.5.4	2.5.4.3.2 5.4.3.8	4.3	8.7	3	7			
"	751–760	8	4.3	4.3.2.5.6	6.5	8.7	3.2	5.4	9.8	4.4.3	7	2	8			
"	761–770	8	3	7.6	6.5	7	3.2	5.2.4	8	4.3	7	5	5	10	20	1: 2.00
10	771–780	9.7.8	4.3	7.6	6.5	8.7	3.2	5.4	8	4.3	8.7	1	9			
"	781–790	8.7	4.3	7.6	6.5	8.8.7	2	5.4	8	4.2.4.3	7	3	7	4	16	1: 4.00
11	791–800	8	1.4.3	7.6	1.3.6.2.6.5	8.7	3.3.2	5.4	8	4.3.	8.7	2	8	2	8	1: 4.00

TABLE VI

RESULTS FOR RAT B, OUTBRED FEMALE, IN PROBLEM 2

Date	No. of trials	S. 1 7.**8**.9	S. 2 1.2.**3**.4	S. 3 3.4.5.**6**.7	S. 4 1.2.3.4.**5**.6	S. 5 4.5.6.**7**.8	S. 6 1.**2**.3	S. 7 2.3.**4**.5	S. 8 1.2.3.4.5 6.7.**8**.9	S. 9 1.2.**3**.4	S. 10 3.4.5.6.**7**.8	R	W	R	W	Ratio of R to W
June 30	1– 6	7.7.7.8	4.2.1.1.2 1.2.2.2.3	2.2.2.2.2 2.2.7*	3.2.1.6.5	1.8.8.4*	2					1	5	1	5	1: 5.00
July 1	7– 13	8	4.3	2.2.3.5 3.6	6.2.2.1.1 1.4.1.3.5	4.6.4.6.8 4.4.8.6.7	3.1.1.2	2.2.3.3.2 3.2.3.3 2.2.5.4				1	6	1	6	1: 6.00
2	14– 23	7.7.9.8	4.2.1.4 1.4.3	2.7.2.3.2 7.2.3.7 3.3.5.6	4.2.1.3.1 2.3.1.6.1 3.1.6.5	4.8.8.4 4.6.8.7	3.1.1.3.2	3.2.4	2.1.3.7.1.6 1.4.3.4.3.9 2.7.1.4.8	1.4.4.1.3	8.3.3.7	0	10	0	10	0:10.00
6	24– 33	7.8	3	7.2.2.4.6	6.3.2.6.2 1.6.1.4.3 1.2.6.1.4 1.1.3.1.6 1.2.4.1*	8.4.8.4 4.4.7	3.1.2	5.4	2.5.7.8	4.1.1.4.3	5.4.3.6.7	1	9	1	9	1: 9.00
7	34– 43	7.7.7.9 7.8	4.2.1.4 1.3	2.4.2.4.7 4.3.4.5.6	4.3.2.4.6 1.3.1.5	8.7	1.3.1.1 1.2	2.2.3.5 3.2.3.4	3.4.5.6 7.8	2.1.3	5.4.5.4 5.6.7	0	10	0	10	0:10.00
8	44– 53	7.7.9.7 9.7.8	4.1.2.3	7.7.6	4.3.4.3.2 1.3.4.5	4.6.7	3.2	2.3.2.3.4	3.4.5.6.5 3.5.6.9.1 3.9.9.1.8	4.3	3.5.3.4 3.6.7	0	10	0	10	0:10.00
9	54– 63	7.8	4.4.1.4 2.1.3	4.6	4.3.4.5	4.6.7	2	5.4	4.3.4.3.5 4.3.2.3.4 6.4.3.5.6 4.5.6.3.9 1.4.3.6.5 4.1.3.7.1 4.8	1.3	3.3.6.8.6 3.4.6.7	1	9	1	9	1: 9.00
10	64– 73	7.7.9.7 7.8	3	3.5.3.2 5.4.5.6	4.5	6.7	2	2.3.2.2 3.4	4.5.2.3.4.6 2.3.4.5.2 1.3.6.5.8	2.3	5.3.4.7	2	8	2	8	1: 4.00
13	74–83	7.7.9.7.8	2.4.2.3	2.3.5.6	3.4.6.1 2.4.6.5	6.4.4.7	2	3.4	7.6.5.6 7.8	4.3	5.3.4.5 4.6.7	1 1	9 9	1 1	9 9	1: 9.00 :1 9.00

TABLE VI—*Continued*

RESULTS FOR RAT B, OUTBRED FEMALE, PROBLEM 2

Date	No. of trials	S. 1 7.8.9	S. 2 1.2.3.4	S. 3 3.4.5.6.7	S. 4 1.2.3.4.5.6	S. 5 4.5.6.7.8	S. 6 1.2.3	S. 7 2.3.4.5	S. 8 1.2.3.4.5 6.7.8.9	S. 9 1.2.3.4	S. 10 3.4.5.6.7.8	R	W	R	W	Ratio of R to W
July 14	84– 93	7.8	4.4.1.2.3	4.5.6	2.3.4.5	7	3.1.2	5.4	1.2.1.3.4 5.6.7.8	4.2.3	7	2	8			
"	94–103	9.7.8	4.3	3.2.3.4.5 7.4.2.1 2.4.5.6	3.2.3.5	7	3.2	6.4	3.4.5.7.5 6.7.5.2.4 5.6.8	4.4.2.3	3.4.6.7	1	9	3	17	1: 5.66
15	104–113	7.7.8	2.3	6	3.4.5	4.5.6.7	2	5.4	4.5.6.7.8	4.4.1.3	8.3.4.5.6.7	2	8			
"	114–123	7.8	4.3	4.5.6	4.5	5.6.7	3.3.2	3.4	7.5.6.7.8	3	7	2	8	4	16	1: 4.00
16	124–133	7.8	2.3	6	6.6.5	5.6.7	3.3.3.3 3.1.2	5.5.5.5.4	7.8	4.2.3	5.3.4.5 6.7	1	9			
"	134–143	7.8	4.4.4.4 4.4.3	6	5	6.6.7	3.3.3.3.3.3 3.3.3.3.2	5.5.5.5 5.2.3.4	7.8	4.4.4.1 2.3	7	3	7	4	16	1: 4.00
17	144–153	7.8	4.4.2.3	7.7.7.2.3 2.3.4.5.6	5	8.8.5.6.7	3.3.1.2	5.3.2.3.4	4.5.4.9.1.2 3.4.5.6.7.8	4.3	8.8.8.5 6.7	1	9	1	9	1: 9.00
18	154–163	7.8	4.2.3	6	5	5.4.5.6.7	3.3.1.2	5.5.2.3.4	7.8	4.2.3	8.3.4.5.6.7	2	8	2	8	1: 4.00
19	164–173	7.8	3	4.5.6	6.4.2.3 4.5	4.5.6.5 6.7	3.3.1.2	5.3.4	5.6.4.5 6.7.8	4.2.3	6.7	1	9			
"	174–183	8	4.4.3	7.2.3.4.5.6	2.3.4.5	5.6.7	3.2	4	7.8	4.3	7	3	7	4	16	1: 4.00
20	184–193	8	4.4.2.3	5.6	4.5	5.7	3.2	4	7.8	4.4.1.2.3	7	3	7			
"	194–203	7.8	4.3	3.4.5.6	4.5	6.7	3.2	4	4.5.6.7.8	4.3	5.6.7	1	9	4	16	1: 4.00
21	204–213	7.8	4.2.3	6	4.5	5.6.7	3.2	3.4	7.8	4.3	5.6.7	1	9			
"	214–223	7.8	4.3	4 5.6	4.3.4.6.4.5	8.6.7	2	2.3.4	5.6.7.8	4.3	7	2	8	3	17	1: 5.66
22	224–233	7.8†	4.3	4.5.6	5	6.7	3.2	4	4.5.8	3	5.6.7	3	7			
"	234–243	7.8	4.3	4.5.6	5	5.6.8.7	3.2	5.4	3.4.6.7.9 1.3.6.8	4.3	5.7	1	9	4	16	1: 4.00
23	244–253	7.9.7.8	4.4.3	4.5.7.6	4.4.4.3.5	4.5.7	3.2	2.4	5.6.8	3	4.3.4.6.5.7	1	9			
"	254–263	9.7.8	2.3	4.6	4.5	4.4.6.5.7	3.2	4	4.3.2.1.3.2 4.3.2.1.1.4 3.5.4.6.8	1.3	4.3.3.5.7	1	9	2	18	1: 9.00
24	264–273	8	3	5.7.6	4.6.5	4.6.5.4 4.6.5.7	3.2	4	5.4.3.2 4.6.8	2.4.3	6.8.7	3	7	3	7	1: 2.33

26	274–283	8	2.3	6	5	4.6.7	3.2	5.4	6.7.6.5 9.1.8	4.3	5.4.6.5 6.5.4.7	3	7	3	7	1: 2.33
27	284–293	9.7.9.8	4.3	4.5.4.3.4 3.2.4.3 5.4.7.6	6.5	4.7	3.2	5.4	4.6.8	4.3	4.8.3.5.4.3 4.5.4.3.5.3 6.8.6.8.7	0	10			
"	294–303	7.9.7.7 7.8	4.3	4.6	6.5	6.5.7	3.2	5.4	4.3.2.1 7.6.8	2.4.3	4.3.5.7	0	10	0	10	0:10.00
28	304–313	8	4.3	6	5	4.4.6.8.7	3.2	5.4	5.4.3.4 6.5.7.8	4.3	3.5.6.5.4 3.5.8.7	3	7	3	7	1: 2.33
29	314–323	8	4.3	6	5	4.4.6.5.7	3.2	5.4	5.7.8	3	4.3.6.5.4.3 6.3.5.4.3.7	4	6			
"	324–333	7.9.7.8	4.3	6	5	5.4.6.5 4.7	3.2	4	9.4.3.2 1.7.8	4.3	4.6.7	3	7			
"	334–343	7.8	3	6	4.6.5	6.5.4.3.7										
							3.2	2.4	5.4.3.6 5.4.3.2 1.6.8	3	3.4.3.6.8 3.4.3.5 6.8.6.7	3	7	10	20	1: 2.00
30	344–353	8	4.3	5.4.3.2 7.6	4.5	4.6.8.6 8.7	3.2	4	6.1.3.5 7.6.8	4.3	7	3	7	3	7	1: 2.33
31	354–363	8	4.3	6	5	6.5.5.4 6.5.4.7	3.2	5.4	4.3.8	4.3	3.6.5.4.3 5.4.3.6.8 3.5.4.3.7	3	7	3	7	1: 2.33
Aug. 4	364–373	7.8	4.3	5.4.3.2.5 5.4.3.2.5 5.4.3.2.4 3.5.4.7.6	5	4.6.7	3.2	3.2.4	4.3.2.4 3.2.5.9.8	1.4.3	4.6.5.4 3.5.4.3 6.5.7	1	9			
"	374–383	7.7.9.7.8	4.3	6	5	4.7	3.2	3.2.2.5.4	5.9.1.6.8	2.4.3	5.8.7	2	8	3	17	1: 5.66
5	384–393	8	4.3	3.2.4.3.2.6	3.2.1.5	4.7	3.2	4	2.1.8	3	4.3.7	3	7			
"	394–403	7.9.7.9 7.9.7.7 9.7.8	2.4.3	4.3.2.6	4.3.2.6.5	4.7	3.2	3.2.4	8	4.3	3.6.5.4.3 5.4.6.8 6.5.4.7	1	9			
"	404–413	8	3	5.4.3.4 3.6	5	6.5.4.7	3.2	3.2.5.4	4.3.2.7.4 4.3.2.6.8	3	6.5.4.3 6.8.7	4	6			
"	414–423	9.7.9.7.9 7.7.9.7.9 7.9.7.9.7 9.7.9.9.7 7.8	4.3	5.4.3.2.6	3.2.6.5	5.4.8.7	3.2	3.2.5.4	3.2.1.6.5 4.3.2.8	4.3	4.3.8.7	0	10	8	32	1: 4.00

TABLE VI—*Continued*

RESULTS FOR RAT B, OUTBRED FEMALE, PROBLEM 2

Date	No. of trials	S. 1 7.8.9	S. 2 1.2.3.4	S. 3 3.4.5.6.7	S. 4 1.2.3.4.5.6	S. 5 4.5.6.7.8	S. 6 1.2.3	S. 7 2.3.4.5	S. 8 1.2.3.4.5 6.7.8.9	S. 9 1.2.3.4	S. 10 3.4.5.6.7.8	R	W	R	W	Ratio of R to W
Aug.																
6	424–433	8	4.3	4.3.2.7.6	3.2.1.6.5	4.6.5.8 5.4.8.7	3.2	4	4.3.2.7.6 5.4.3.2.6 5.4.3.4 7.9.1.8	4.3	6.5.4.3 8.4.7	2	8	2	8	1: 4.00
7	434–443	7.9.7.9 7.7.7.8	4.3	6	4.3.2.5	5.4.4.7	3.2	5.4	5.4.3.2 4.7.8	4.3	6.5.4.6.8 3.6.5.7	1	9			
"	444–453	7.9.7.9 7.7.9.7 9.7.8	3	4.3.6	6.5	4.6.8.7	3.2	3.2.5.4	3.2.4.3.2 4.3.2.4 3.2.4.3 5.7.6.8	4.3	6.5.7	1	9			
"	454–463	7.9.7.9 7.9.7.8	3	7.6	5	5.4.7	2	3.2.5.4	6.5.7.6.8	4.3	3.5.5.7	3	7	5	25	1: 5.00
9	464–473	8	4.3	4.3.2.5.4.3 2.5.4.7.6	4.3.6.5	4.6.5.4.7	3.2	3.2.5.4	6.5.4.3 5.6.8	3	3.5.3.6 8.7	2	8	2	8	1: 4.00
10	474–483	7.8	4.3	7.6	3.2.1.4 3.2.5	4.6.5.7	2	5.4	2.1.5.4 7.6.8	2.1.4.4 4.3	6.8.7	1	9	1	9	1: 9.00
11	484–493	8	4.3	3.2.5.4.6	4.3.2.5	4.7	3.2	3.2.5.4	3.5.7.6.8	3	3.7	2	8	2	8	1: 4.00
12	494–503	8	4.3	4.3.2.4 7.6	4.3.6.5	4.7	3.3.2	2.5.6.4	4.6.8	4.3	3.7	1	9	1	9	1: 9.00
13	504–513	8	4.3	7.6	6.5	7	3.2	5.4	8	3	3.6.8.7	4	6	4	6	1: 1.50
14	514–523	8	4.3	3.2.6	2.1.6.5	5.4.7	3.2	3.5.4	4.3.2.5.7.8	3	3.5.6.8.7	2	8			
"	524–533	7.8	4.3	4.3.2.4 3.2.6	6.5	4.7	3.2	5.4	9.8	4.3	6.5.7	0	10	2	18	1: 9.00
16	534–543	7.9.8	4.3	4.6	4.5	5.7	3.2	4	8	4.3	7	3	7	3	7	1: 2.33
17	544–553	7.9.8	4.3	5.4.3.7.6	5	8.7	3.2	4	3.2.6.5.7.6 5.7.6.5.8	3	7	4	6	4	6	1: 1.50
18	554–563	7.9.8	4.3	4.3.2.7.6	4.3.2.7.6.5	7	3.2	5.4	5.4.3.2.8	3	7	3	7	3	7	1: 2.33
20	564–573	8	4.3	5.4.3.2.7.6	4.3.2.5	5.7	3.2	5.4	5.7.9.8	4.3	8.7	1	9			
"	574–583	8	3	5.4.3.2.6	5	4.7	3.2	5.4	4.3.6.8	4.3	6.5.7	3	7	4	16	1: 4.00
21	584–593	8	4.3	5.4.3.5 4.7.6	3.2.6.5	4.7	3.2	4	8	4.3	5.4.3.6 5.7	3	7	3	7	1: 2.33

23	594–603	7.9.8	3	3.2.5.7.6	3.6.5	5.8.7	1.3.2	5.4	7.9.7.6.8	4.3	8.8.6.7	1	9			
"	604–613	8	4.3	5.4.5.7.6	4.6.5	4.6.8.7	3.2	4	8	4.3	8.4.3.8.7	3	7	4	16	1: 4.00
24	614–623	8	4.3	4.3.2.5 7.8.6	4.3.6.5	6.8.9.7	3.2	5.4	4.6.5.8	4.3	4.7	1	9			
"	624–633	7.9.8	4.3	6	4.3.2.6.5	5.8.7	3.2	4	7.6.5.8	4.3	5.8.7	2	8	3	17	1: 5.66
25	634–643	7.9.8	4.3	6	5	4.7	3.2	4	5.4.3.2.9.8	4.3	5.4.3.8.7	3	7			
"	644–653	8	4.3	6	5	5.4.8.7	3.2	5.4	7.6.5.8	4.3	5.4.3.7	3	7	6	14	1: 2.33
26	654–663	7.9.8	4.3	6	4.3.2.1 6.5	4.8.7	3.2	3.2.5.4	4.3.2.7.6 5.7.6.9.8	4.3	3.6.5.8.7	1	9	1	9	1: 9.00
27	664–673	7.9.8	4.3	4.3.6	4.3.2.6.5	5.4.7	3.2	3.2.5.4	2.8	3	5.4.3.7	1	9	1	9	1: 9.00
30	674–683	7	4.3	3.2.7.6	3.6.5	4.5.7	3.2	4	5.4.3.6.5 4.3.2.1 3.7.6.8	4.3	3.8.7	2	8			
"	684–693	7.8	3	2.6	5	5.4.6.5 4.8.7	3.2	5.4	3.2.8	4.3	8.7	2	8	4	16	1: 4.00
31	694–703	8	3	7.6	6.4.3.6.5	7	3.2	3.2.5.4	5.4.3.6 5.7.8	3	5.4.7	4'	6	4	6	1: 1.50
Sept. 1	704–713	7.8	3	5.4.3.5 4.3.6	3.2.6.5	4.7	3.2	2.5.4	3.6.5.7 6.8	4.3	4.5.4.7	1	9			
"	714–723	7.8	3	5.4.3.6	2.5	4.7	3.2	4	8	3	4.3.7	4	6	5	15	1: 3.00
2	724–733	7.9.8	3	2.6	3.6.5	4.6.5.7	2	3.5.4	2.5.4.6 5.7.6.8	3	4.3.5.7	3	7			
"	734–743	7.8	3	3.2.6	5	4.7	3.2	5.4	3.2.5.4.3.5 4.3.6.9.8	4.3	5.4.3.7	2	8			
"	744–753	7.8	4.3	5.7.6	3.6.5	5.7	2	5.4	7.8	1.4.3	7	2	8	7	23	1: 3.28
3	754–763	7.8	4.3	6	4.3.6.5	5.4.6.8.7	2	5.4	9.1.5.7.8 6.1.5.7.8	4.3	5.4.5.7	2	8			
"	764–773	7.8	4.3	3.2.5.7.6	3.5	6.5.8.7	2	5.4	8	4.3	4.3.6.5.7	2	8			
"	774–783	7.7.9.7.9.8	2.4.3	6	6.5	4.4.7	3.2	5.4	7.6.8	1.4.3	4.3.6.5.7	1	9			
"	784–793	7.9.8	4.3	6	4.3.6.5	8.7	3.2	5.4	4.3.2.5 7.6.8	3	4.3.7	2	8	7	33	1: 4.71
4	794–803	7.8	3	4.3.2.7.6	3.2.6.5	6.5.7	3.2	3.2.5.4	3.2.8	3	3.7	2	8			
"	804–813	7.9.8	4.3	6	4.3.2.6.5	5.4.7	3.2	3.2.5.4	5.4.7.6.8	4.3	4.3.5.7	1	9			
"	814–823	7.9.8	4.3	6	4.3.2.6.5	4.7	3.2	3.2.5.4	4.3.7.9 3.2.5.8	3	4.3.8.7	2	8	5	25	1: 5.00
5	824–833	8	4.3	4.3.7.6	4.3.6.5	5.7	3.2	5.4	4.3.2.5.4 5.7.6.8	4.3	3.6.8.7	1	9	1	9	1: 9.00
7	834–843	8	3	3.2.5.7.6	4.3.2.6.5	5.4.7	3.2	4	6.1.5.4.8	4.3	3.7	3	7			
"	844–853	7.9.8	4.3	6	4.3.2.6.5	4.8.7	3.2	4	6.5.4.8	4.3	4.3.8.4 3.8.7	2	8			

TABLE V1—*Continued*

RESULTS FOR RAT B, OUTBRED FEMALE, IN PROBLEM 2

Date	No. of trials	S. 1 7.**8**.9	S. 2 1.2.**3**.4	S. 3 3.4.5.**6**.7.	S. 4 1.2.3.4.**5**.6	S. 5 4.5.6.**7**.8	S. 6 1.**2**.3	S. 7 2.3.**4**.5	S. 8 1.2.3.4.5 6.7.**8**.9	S. 9 1.2.**3**.4	S. 10 3.4.5.6.**7**.8	R	W	R	W	Ratio of R to W
Sept. "	854–863	7.9.8	4.3	7.6	2.6.5	5 4.8.7	3.2	3.2.5.4	3.2.5.7 6.5.7.8	3	3.7	1	9	6	24	1: 4.00
8	864–873	7.9.8	2.1.4.3	4.3.6	3.2.6.5	5.4.7	3.2	4	4.3.2.7 6.5.4.8	1.4.3	8.7	1	9			
" "	874–883 884–893	7.9.8 7.9.8	3 3	3.2.7.6 6	4.3.2.6.5 6.5	5.4.8.7 5.4.7	3.2 3.2	4 5.3.2.5.4	3.2.1.5.8 4.6.5.4 3.6.7.8	1.4.3 2.4.3	3.7 7	2 3	8 7	6	24	1: 4.00
9	894–903	7.8	4	2.7.6	3.2.6.5	5.8.7	3.2	4	2.7.6.8	3	3.7	3	7	3	7	1: 2.33

* Refused to work; laid down.

† Ten seconds punishment introduced.

a correct first choice in any trial is 1-5 and the probable ratio or correct to incorrect first choices on a given day's trials, apart from experience, is 1 to 4. With C this was exactly the ratio for the first day's trials. It was also the ratio for the last day's trials. B started with a ratio of 1 to 5 which was reduced to 1 to 2.3 at the end, but there was no constancy in the results and the reactions were so manifestly random that further training seemed useless.

Although the rats failed to solve the problem, certain important reactive tendencies were noted. C began the problem 4 days after the check series on problem 1. The old habit which was manifest at the outset disappeared gradually and was little in evidence after 100 trials. The tendency to enter the same (incorrect) door two or more times in succession also disappeared at about the same period in the training. Between trials 100 and 500 there was frequently a tendency to make several random choices and then work from right to left, entering consecutive doors successively. (cf, trials 133, 184, 338, 444). After this stage the tendency was not so manifest, for the first random choice was nearer the left. This latter fact also heightened the probability of a first correct random choice, which doubtless accounts for the higher scores in many of the later series. After trial 250 there began to appear a tendency to enter the left door and *then the second from the left*. (cf. trials 251, 254, 256, 257). This tendency was increasingly manifest throughout. In trials 721-730 and 771-780, 8 out of 10 trials showed this type of reaction. The animal did show a definite tendency to turn to the left on leaving the entrance box, and often appeared to go directly to the door at the extreme left of those that were open. Whether it was merely this habit that was operative and the second choice naturally involved the neighboring door, or whether the rat formed the habit of going into the end compartment and then the second can not be definitely stated.

B was set at problem 2 without prior training in problem 1. Consequently there was no previous habit to break. B was likewise very active. At the outset the same door would be entered repeatedly (cf. trial 3), but this was seldom the case after 150 trials. There soon appeared a tendency after an incorrect choice to enter alternate doors going rightward or to enter consecutive doors going leftward. Sometimes the one tendency was followed by the other. (cf. trials 167, 268). After trial 270 there some-

times appeared the opposite tendency,—to go leftward entering alternate or rightward entering consecutive ones. (cf. trial 271). These two tendencies to enter consecutive or alternate doors going in either direction were somewhat manifest throughout.

At trial 224 the period of punishment for B was increased to 10 seconds and soon after that she learned to stick her nose under the door (which was raised 3-16 inch from the floor to protect the tail), and wiggle out on her side before the 10 seconds were up. The direction in which she then turned appeared to depend much on her orientation as she came out of the compartment in this way. On the whole, B showed less systematic attack upon the problem than C, choosing more palpably at random and getting fewer successes on the second choice.

SUMMARY

1. The first two standard multiple choice problems were presented to white rats. These problems may be defined in terms of the constant relation of the correct mechanism to the varying group of mechanisms as: (1) the first at the right end of the series; (2) the second from the left end of the series.

2. One inbred and two outbred rats five months old solved the first problem in 200 trials or less. Another inbred individual two months younger required 350 trials. The indications are that visual tactual and kinaesthetic guidance sufficed for the formation of the habit.

The second problem proved insoluble for the two rats which attempted it. Both acquired a general tendency to turn toward the left, thus more frequently making a correct random choice, but the relation of secondness from the left was evidently beyond them.

3. There were two noticeable reactive tendencies manifested by one rat. In problem 1 she would at times become oriented very suddenly, dash to the right end and then across to the correct door. In problem 2 she repeatedly entered the left door and then the second from the left. Although it is tempting to ascribe these tendencies to a higher level of behavior, it would seem better to explain the first in terms of kinaesthetic units and the second by the acquisition of the habit of choosing the left door,—the following choice most naturally involving the adjacent correct door.

THE LEARNING OF A MAZE BY GOLDFISH[1]

E. P. CHURCHILL, JR.

The study of the behavior of fish when confronted by a problem such as a maze is rendered of considerable importance by the fact that in these animals the pallium of the brain is undeveloped. Various investigators, while working on the problem of color discrimination in fish, have incidentally shown that these animals possess associative memory and can form simple habits. Mention will, however, be made here only of literature that deals more strictly with the problem of habit formation.

Triplett[2] found that perch, after several trials, cease to try to reach minnows on the opposite side of a glass partition. After the removal of the partition the perch made no attempt to pass the point where the partition had formerly been placed.

Thorndike[3] described in a general way the learning of a maze by Fundulus. He found that this fish sought the shaded part of the tank. To gain this he caused them to swim through openings in partitions placed across the tank. He found that the time required for the trials lessened from day to day.

Goldsmith,[4] working chiefly with Gobius and Gasterosteus, showed that these fish have a well marked and enduring topographical memory. If fed at a certain point in the tank they soon learned to come there and this habit persisted after 18 days lapse of practice. She also found that they had a memory of direction. A simple maze was constructed by placing across the aquarium a glass partition pierced by an opening. The stimulus used was the nest, to which the fish endeavored to return. On the first day the fish learned in 3.5 hours to go directly through the opening to the nest. The number of trials is not recorded. The next day the fish relearned the maze in

[1] From the Laboratory of Animal Behavior, Johns Hopkins University.

[2] Triplett, N. Educability of the perch. *Amer. Jour. Psych.*, 1901, **12**, 354 et seq.

[3] Thorndike, E. L. Animal intelligence. New York, 1911, Chap. IV, pp. 169-171.

[4] Goldsmith, M. Les Réactions physiologiques et psychiques des Poissons. *Bull. de l'Institut général psychologique*, Paris, 1914. **14**, 97-228.

.25 hours. The time lessened from day to day though the fish had to a certain extent to relearn the maze each day. If a partition of wire netting with openings 5 mm. square were used the fish swam at once through the passageway and to the nest. She thought the fish saw the netting and the opening through it and consequently was guided by the sense of sight. From various experiments she concluded that the illumination, distribution of light and shade, and the play of light on the walls of the container guided the fish. The objects in and about the maze were not made use of as data by the animals. The faculty of "motor memory" may be possessed by the fish but she thought it was a less important factor in solving the maze than the sense of sight. She also worked extensively on the discrimination and memory of colors and form in fish.

In view of the fact that the behavior of fish in a maze has received less emphasis than the other features of the work with this animal, it seems of interest to record an attempt at a quantitative estimate of the ability of fish to learn to run a maze of a moderate amount of difficulty.

Goldfish (*Carassius auratus*) were used because they live readily in aquaria and can subsist on the prepared food which does not diffuse through the water. As food was the stimulus used this latter point was of importance. Eight fish were used. These varied in length from individuals measuring 4.5 cm. to one of 5.5 cm. They were kept in individual numbered pens. One trial a day was given. The food was cut into squares about 4 mm. across. One such square was used for each trial and this was the only food the fish received until the next day.

A diagram of the maze used is shown in Fig. 1. It was of the same general plan as the one used by Thorndike and consisted primarily of a tank with glass sides and ends and measured 66.25 cm. in length, 37.5 cm. in width and contained water to the depth of 18 cm. The tank was divided into three compartments (1, 2, and 3, see Fig. 1) of approximately equal size by means of two partitions. In case of two groups of fish the partitions were constructed of wire netting, in the case of the other group they were of unpainted wood. In each partition was a rectangular opening 2.5 cm. square. In the case of the partition between compartments No. 1 and No. 2 the opening was situated at the surface of the water and within 5.6 cm. of

one side of the tank. In the partition between compartments No. 2 and No. 3 the opening was at the bottom and within 6.8 cm. of the side of the tank opposite to the opening of the first partition. With one group of fish the openings were bordered by a black pasteboard band 2.5 cm. in width attached by wire clips to the partition on the side nearer the end of the

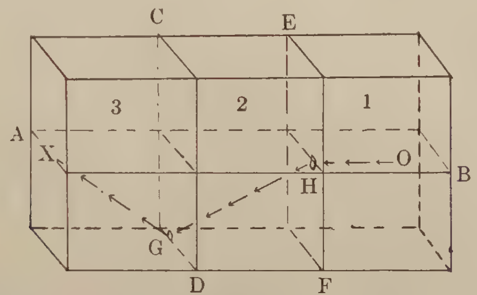

FIGURE 1. Diagram of the maze with the compartments 1, 2 and 3. AB, surface of the water. CD and EF, the partitions. G and H, the openings for the passage of the fish. The food was placed at X and the fish at O. The line of arrows represents the shortest possible route through the maze.

tank where the food was placed. The light was furnished by a 40-watt Mazda lamp suspended over the center of the tank at a distance of one meter above the surface of the water. The food was placed in compartment No. 3, on the surface of the water, midway of the glass forming the end of the tank and touching the glass where it would remain until found by the fish. The observer sat either near the end of the tank where the food was placed or at a point entirely removed from the range of vision of the fish.

The fish were given preliminary trials with no partitions in the maze. At the expiration of about a week the fish would come fairly regularly and take the food which they found by the sense of sight. The partitions were then put in and daily trials started. The procedure was as follows: Sunlight was excluded from the room and the light turned on. About fifteen minutes were allowed to elapse in order to give an opportunity for the fish to become adapted to the light. A square of food was placed in the position described above. Then fish No. 1, e.g., was lifted from its pen by means of a small net and placed gently in the center of compartment No. 1. The time was noted at that instant. The fish was watched until it had swum

through the maze and the time noted the instant it touched the food. The fish was allowed about five minutes in which to eat the food and was then removed from the maze.

Group I consisted of four fish which were used with the wire partitions with no visual signs about the openings. The curve representing the averages of the length of time of their trials is shown in Fig. 2. Three of these fish were given 60 trials, the fourth 46. In Fig. 2 the part of the curve enclosed in parentheses represents the averages for three fish only. It will be seen that the average time fell from 105 minutes for the first trial to 3 or 4 for the last trials. After the thirty-sixth trial the time never exceeded 5 minutes. The elevation at the point marked "x" is partly due to the exceedingly poor record of two individuals after the group had undergone a cessation

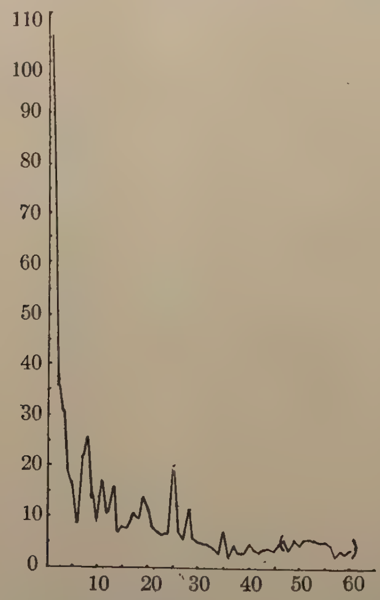

FIGURE 2. Curve for Group I representing the average time of the daily trials. The elevation at x was caused by the poor record of two fish after a cessation of practice of two weeks. The portion enclosed in parentheses represents the time for three fish only. The abscissae indicate trials, the ordinates, time in minutes.

of practice of two weeks duration. Individual variations were quite noticeable. Fish No. 1 consumed 240 minutes during its first trial, while No. 2 required only 17, but went as high as 80

on its eighth trial. Fish No. 3 was the best of the group. Its last five trials, the forty-second to forty-sixth inclusive, never exceeded one minute in length while the last three were of a duration of thirty seconds each. The average physiological limit of the group seemed to have been reached at about the thirty-sixth trial, though the habit bore up well for the remaining trials.

The members of this group apparently used the sense of sight very little in running the maze. They would repeatedly swim directly past the opening without passing through. The interstices of the wire netting were fairly large, three to every 2.5 cm., and it is doubtful if the fish discriminated by the sense of sight between these and the openings intended for their passage. As far as could be observed they found the passageway by playing about the netting and thrusting the head into the interstices until the opening was hit upon, this being large enough to allow their passage. They gradually learned to explore more and more closely about the opening and thus the time was reduced. Toward the last they swam fairly accurately to the opening and passed through with very little nosing about. This was especially true when they were passing through the second partition. The passage from compartment No. 1 to No. 2 usually required more time than that from No. 2 to No. 3. This was no doubt due to the fact that the fish had to orient itself after being placed in compartment No. 1. The fish of this group very seldom went back into the compartment from which they had just come.

In Group II two fish were used with the wire partitions provided with the black bands about the openings. The curve for this group is shown in Fig. 3. Forty trials were given in this case. The curve is very abrupt in its initial part. Neither fish succeeded in running the maze the first day. The number, 405, toward which the arrow points in Fig. 3, represents the average time the fish were left in the maze during the unsuccessful attempts. On the next day one fish ran the maze in 7 minutes and never consumed more than 15 minutes at any later trial. As far as could be seen the failure of the first trial was due to fear on the part of the fish. They avoided the region of the openings during the first trial. However, after the first few trials the improvement was more rapid and the final achievement

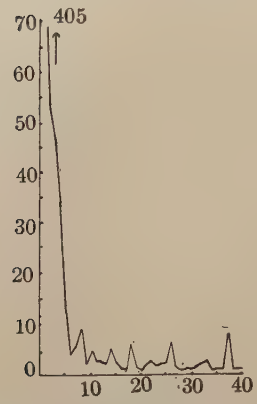

FIGURE 3. Curve for Group II, the position of the beginning of the curve being indicated by the arrow. The abscissae represent trials, the ordinates, time in minutes.

greater than was true of Group I. It will be seen that the curve descends more rapidly and farther and remains lower than does that of Group I. The fish went back to a previously occupied compartment more frequently than did the members of Group I.

Group III was made up of two fish which were used with the wooden partitions. Their initial trials, although successful, required considerable time (Fig. 4). This seemed to be due to

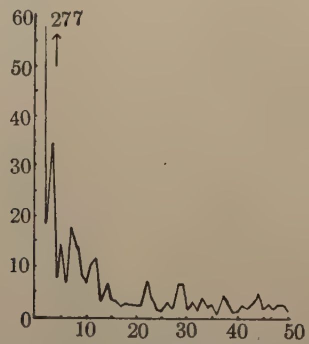

FIGURE 4. Curve for Group III. The abscissae represent trials, the ordinates time in minutes.

the fact that the fish did not play about the dark wooden partitions to any extent. When they did reach a point an inch or two directly before the opening they usually went through. The reverse passage of the openings was made much more

frequently than in either of the previous groups. The record of this group is better than that of Group I, but not as good as that of Group II (Fig. 5). The chief difference was that their improvement was not quite as rapid, their final attainment being as great as that of Group II. Fig. 5 shows the three curves plotted together, the trials being grouped in fives. The openings in the wooden partitions were not as conspicuous from

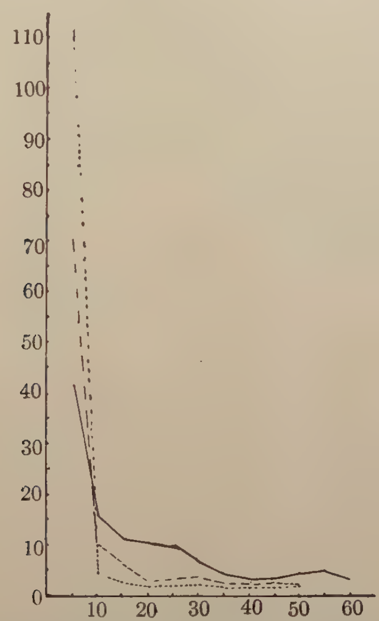

FIGURE 5. Curves for the three groups plotted together for purposes of comparison, the trials being grouped in fives. Continuous line represents Group I, dotted line Group II, broken line Group III. The abscissae represent trials, the ordinates, time in minutes.

a distance, unless the fish were directly in front of them, as were the black-banded openings. This may account for the fact that the record of Group III was not as good as that of Group II.

Retention tests were tried with two fish. In Group I practice with one individual was allowed to cease for thirteen days after the forty-sixth trial. The record for the last three trials was 30 seconds each. After the interim the first trial required 7.5 minutes. The time dropped to one minute on the fifth trial. One individual of Group II was given a retention test

of thirteen days after the fortieth trial. The time rose from one minute to 3.5, but fell at the third trial to one minute.

Some tests were made with the positions of the openings in the partitions reversed so that the fish had to swim down to one side when leaving compartment No. 1 and up to the other side when leaving No. 2. One individual from Group I, which had been running the maze in from one to two minutes required 12.5 minutes to run it when thus reversed. The fish tried first the regions where the openings had formerly been situated. An individual from Group II was given a trial in the reversed maze. It tried once at the point where the opening had formerly been but turned then and swam directly to the black-banded opening and passed through. A fish from Group III, when the wooden partitions were reversed, tried quite persistently at the points where the openings has been previously situated before finding them in their new positions.

The fact that in Groups II and III, where the openings were more apparent to the eye, the improvement was more rapid and the final achievement greater than in Group I leads to the conclusion that the sense of sight was a factor in the running of the maze, especially in the earlier trials. However, the fact that the members of Group I learned the maze only a little less rapidly and thoroughly than did those of the other two groups shows that kinesthetic factors were involved in the process. They probably came to function more and more exclusively as the practice went on. That kinesthesia was an important factor is further proved by the behavior when the positions of the openings were reversed and the fish proceeded to the region where they had formerly found the passage-way. The sense of touch also aided, especially in the case where a visual sign was not used and the fish nosed about the netting. As perfection of the habit was more nearly approached the use of the senses of sight and touch fell more and more into the background and when the physiological limit was reached kinesthesia was largely the factor employed.

SUMMARY

Goldfish, although lacking a pallium, are capable of forming a definite habit of a moderate degree of complication and of retaining this habit for some time.

The physiological limit for the running of the maze when daily trials were given was, for Group I, 2 minutes reached on the thirty-sixth trial; for Group II, one minute on the twentieth trial; for Group III, one minute on the thirty-sixth trial. The habit was fairly well retained after 13 days lapse of practice.

The senses of sight and touch were instrumental in the initial steps of the habit formation but later were superseded to a great extent by kinesthesia.

TWO METHODS OF SUBJECTIVE LEARNING IN THE MONKEY *MACACUS RHESUS*

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The studies of the learning processes of monkeys have led to some disagreement as to whether or not monkeys learn by the imitation method or through perseverance of trial and error or by both methods. The researches of Kinnaman, Shepard, Watson, Thorndike, and Haggerty show that the monkey learns principally by the perseverance method, but also, if the problem with which he is confronted is not too complex and contains only such elements or steps to be associated together for success as he has already mastered, by imitation.

A review of the researches of the above observers shows that practically all the studies of the monkey's learning processes have been through the problem method, requiring the monkey to *manipulate in a certain manner or sequence* objects of a general type for which all monkeys have a great natural fondness and interest.

One factor that has made some of the studies of learning not altogether convincing has been the unnaturalness of some of the movements required of the ape and other animals to solve the problem or to imitate another animal's movements. The animal often simply does not have the reactions or reflex systems in its repertory and lacks neurologically the capacity to acquire the necessary movements or associations of movements, or associations of sensations and sensory images, to solve the problem. Also the factor of internal, emotional distractibility has been underestimated. The uneasiness of the subject caused by the nearness of the human is so persistent and reflex in type that it always causes more or less distractibility, presenting a proportionate degree of incoördination, like the pupil who fears his teacher and cannot learn from him, or the uneasiness produced in a speaker by the mere presence of a crowd. For example:

Shepard says that he placed the glass tube and stick in the cage with the animal " to see if he could push out the food in the tube *after his attention had been attracted and he had been shown by the experimenter how the stick was to be manipulated* for obtaining the banana or peanut." Monkeys are not only afraid of a man but are ready to flee when a stick appears in one's hands. Although the monkeys saw the experimentator use the stick from 72 to 228 times, none of them showed any signs of imitation. If, as is most probable, the monkeys were the hosts of even slight fear reactions from the hand or stick, imitation, above everything else, could not be expected. Kinnaman similarly spoke of making *suggestive movements* with a key (an object in the hand) to indicate its necessity in procuring the food. The monkeys did not imitate.

Otherwise this work has so thoroughly covered this phase of the monkey's learning methods that perhaps further contributions are not needed. However, quite by accident the monkeys themselves revealed that they had other problems to master besides the *objective ones* of manipulating objects in proper sequence or manner; problems of a more *subjective* nature, such as when they knew perfectly well what they wanted to do, and in a way, how to do it, and saw how other monkeys performed an act, but to acquire the same results they had to learn how to control and manipulate their own muscles, of the body, arms and hands, in a certain manner.

Since this seems to be an important condition of the learning process of the monkey it is thought to be worth reporting.

The following observations were made from six *Macacus rhesus* monkeys. Three of them, A, B, and C, are immature, well formed and presumably half grown. A and B are males. C is a female. They differ markedly in disposition but a study of their personalities need not be given here, except to state that A is very timid and gives way to the demands of all the others. He is forced to adapt himself to their demands in any other way than by using force.

B is a very active, aggressive monkey and frankly competes for food with any of the others. He rarely fights back at D, E, or F, and I only observed once that he tried to take food from one of the larger monkeys. B dominates A and C. C is very much like B in disposition and used to dominate him,

but ever since F punished C when B, C and F were caged together, B punishes her and she submits to his aggressions.

D, E and F are about matured males. E is the largest and most powerful and dominates the band. D is next in strength and dominates all but E. That is, he punishes all but E. F is not liked by the other monkeys, and they all have preferences for some other monkey than F. F dominates A, B and C.

The studies were conducted in a basement where they live in three cages. Besides one or two boxes, a barrel and a chair, there is no other furniture in the room. My presence during the studies could have had very little influence since they all are used to me. They are more or less timid toward me, but pay practically no attention to me when I am quiet and remain at a distance.

The problem studied was accidentally suggested. The cages are all raised 18-19 cm. from the floor by blocks, one under each corner. There is an aperture about 4 cm. wide and 80 cm. long between the flooring of the cages and the lower horizontal wooden bar to which the screen is attached. This aperture is closed by a movable wooden bar to keep the sawdust in the cage and is easily removed for cleaning the cage and watering. A small wooden box, 25x30x16 cm. happened to be at hand. One evening I noticed some of the monkeys trying to reach to the floor for some peanut shells. It occurred to me to drop a few peanuts into this box and push it up to the cage and see the monkeys reach for the nuts.

A, B and C were in this cage. They promptly reached through the wires into the box but the distance was too great to reach the peanuts. The bar was then removed and A, B and C immediately returned to grab peanuts. B and C returned first and, true to their habits, overlooked the new opening and utilized as before, the nearest wire screen area above the box. They repeatedly reached through the spaces but could not quite touch the nuts. A tried to reach from this place also but was pushed away by B and C, whereupon he tried it lower down and pushed his hand through the horizontal aperture between the floor and the crossbar and then extended his hand into the box containing the nuts. He chuckled his delight as he drew out the nut. Immediately B and C tried this aperture and succeeded in reaching the nuts. (Objective learning through

imitation.) After that they all promptly used the lower space and abandoned the wires for reaching food from this box. They seem to be equally quick at it, often requiring only about one-half a second to make the movement.

The food box was then presented to D, E and F, who were caged together. D, E and F saw A, B and C feed from the box and F may have imitated them, but since he had often reached to the floor before, this is not likely to have been the case. He immediately placed himself in the proper position and reached the food. D and E could not reach the food, although they extended their hands through the proper aperture.

Before relating D and E's methods of finally acquiring the food from the box it is necessary to make clear the type of movement required to reach the food. The extreme simplicity and naturalness of the position necessary to acquire the food should be given the most consideration.

To take a nut from the box the movement of A, B, C and F was simply that of crouching close to the floor on all fours with the body parallel to and near the aperture, then extending the forearm of the arm nearest to the bar through this aperture, pronating the hand so that the palm faces the food and simultaneously pushing the arm through the aperture up to the shoulder. A, B, C and F did this within a few seconds from the beginning and quickly became so expert that they could perform the movement in less than a second. All monkeys learn this crouch in infancy, as do most four-footed animals. It is one of their most natural and frequent positions. To crouch on the perch in this manner and reach over the edge with one hand to scratch another monkey below is a very frequent movement for all of them to make. So in this movement probably no new motor coördinations were required or sensory stimuli given, and on the other hand one of their most frequent positions and movements was necessary to reach the food. One thing must be added, however. When the monkey's head remained above the cross bar and near the wire netting he could see the food while he reached for it; and when he crouched close to the floor and extended his arm through the aperture beneath the cross bar, his face would be beneath the cross bar, and he would be unable to see the food or his hand when he reached. He would have to depend upon touch to orient himself. On

the other hand every monkey is fond of sticking his fingers into places where he cannot see what he touches.

For three months, in which time the problem was placed before the monkey from about a quarter of an hour to an hour at a time on an average of three times a week, D and E were unable to get anything out of this box. Although they had innumerable opportunities to watch and did watch very closely while in the presence of A, B, C, or F, or several, or all of them, or when by themselves. They also tried to solve the problem when alone. It is perhaps needless to add that they were urged to do so by the odor and sight of many tempting fruits, nuts and vegetables, during states of great, little, or no hunger and they were unable to learn. Their efforts to reach into the box at times were perfectly ridiculous and grotesque. They would twist themselves into the most awkward positions, even for a monkey, stand on their hands, pushing their faces into the aperture and hold to the wires with their hind feet, almost standing on their heads, or climb up the wires backwards, turn their backs to the food and try to reach it, twist themselves around and around in a circle, call for the food, get angry, punish the other monkeys and what not.

They were helpless and would probably have starved if their struggles for food had been the sole means of living.

They learned to snatch food from the other monkeys and when this failed, at times they would sit by the box and shake it back and forth or drive the other monkeys away. D and E would often sit by the aperture and watch another monkey reach for the food and then snatch it as he drew it through the aperture. F then adjusted to this by pressing his face into the aperture and pushed the nuts into his mouth without raising his head. When he had several in his pouch he would then dash away.

B would frequently grab food out of the box and dash to the top of the cage and eat it. E would cautiously climb up to get near enough to grab him. As soon as E would be far enough from the box B would dodge him, dash to the box, grab food and be away before E would get back to the box. Occasionally B would make an enticing chuckling sound to E which was very similar to the sound made when wishing sexual play. This

would usually induce E to come away from the box and give B an opportunity to dash by him.

In the beginning the study was not intended for publication, so a count of the distinct attempts to reach into the box was not made. It is safe, however, to estimate that D and E each made more than two hundred, probably twice that number of attempts to reach the food and neither seemed to make any progress. They repeated over and over again about the same futile movements. D and E would both often crouch at right angles to the box, look over the bar into the box and thrust their arms through the aperture up to the elbow. Although they would pronate the forearm they could not bend the elbow to lower the hand into the box, being anatomically impossible in the narrow aperture with the body at right angles to the opening and the head above the bar. They would then usually shake the box back and forth or try to lift it or turn it around.

The observations of two periods are given here to make clear what happened. The period of April 8 is typical of all the periods previous to it. During the period of April 19 D succeeded for the first time in his efforts to obtain food.

OBSERVATIONS

April 8.—D and F are in the cage together. Several prunes were dropped into the problem box. D reached through the aperture to the elbow. F pushed his way to the aperture, crouched and extended his arms through the aperture and helped himself to the prunes. *D crouched right beside F, watching him intently, especially F's hand reaching for food, and he moved his forearm through the aperture the way F did but did not turn his body properly. He clearly tried to imitate F's method of reaching.* (Subjective learning through imitation.) *F grabbed all the prunes.* A few minutes later F grabbed all the nuts and bread without exception. This is about what occurred each time the problem was tried throughout twelve weeks.

April 19.—D and F in a cage together. One dried peach was dropped into the box. F grabbed it. D pursued F to take it from him. Piece of dried bread dropped into the box. F grabbed it. Bread again dropped into the box before F finished eating. D turned the box around and pulled it back and forth;

placed himself in many awkward positions. Extended his hind legs and body in a vertical position, holding to the wire netting with his hind feet. He turned around, finally standing upside down in a vertical position with his head near the aperture. He succeeded in scratching the bottom of the box but could not reach the food. Then he seemed to lose his balance and fall over on his side. This accidental position was correct for reaching the food. He pulled out the piece of bread. He ate the bread. A peach was lying in the box. He tried repeatedly to reach it but could not and did not assume the proper position again. F grabbed the peach. Handful of peanuts were dropped into the box. F grabbed most of them.

Now D tried all types of movements, squirming into one position after another in a most useless and fruitless manner. Twice his body happened to get into the proper position to easily reach the food but each time he changed his reaching hand from the one beside the aperture to the one on the opposite side of his body. He continued to try, raised his body and hind legs into the upside-down vertical position, holding on to the screen with his hind feet; then reached into the aperture with the off side hand and pressed his face into the aperture. His hand touched the nuts and he extracted four despite the awkward position of his hand. He then left the box to eat. Then he returned to get more nuts and seemed to be unable to reach them or resume his old position. He shook the box fruitlessly.

The next day the observations were repeated and D seemed to learn all over again. He went through a series of trials and errors and finally, more quickly than the day before, assumed his unique, awkward method. This method he developed until he became fairly dexterous.

He places his right hand on the wires just above the cross bar to steady himself and raises his body and hind legs above his head and shoulders, placing himself in a more or less vertical position. The abdomen and chest are pressed against the wires. He extends the left hand, which is on the opposite side of the body, through the aperture, this allows the arm to remain nearly straight, and *scrapes the back of the fingers* over the box floor until he happens to touch a nut. He required 5, 3, 3, 4, 10, 10 and 156 seconds for each trial to extract a nut.

The presence of F bothered D somewhat instead of assisting him to learn. But D was often tried alone and rarely did more than to pull the box around or twist himself into awkward positions.

E seemed to have even more difficulty in learning than D, although he had the longest arms of the six monkeys. Like D, he was given the opportunity to watch B, C and F take food from the box. He seemed to watch very closely but he never showed so clearly efforts to *imitate* as D tried to imitate F. That is he never sat beside B, C or F and moved his arm forward automatically as the other monkey's arm passed into the box.

Most of E's trials were made in company with B or alone. He would usually drive B away and shake the box back and forth or extend the arm to the elbow through the aperture. B probably interfered with E's learning process because of his quick dashes to the box and disconcerting eating when E was hungry. E preferred to take food from the others rather than try to procure his own. Despite this he made a great many trials with no result. Like D he seemed to bungle about the wires, twisting himself around in the most awkward positions. until he fairly fell into a crouch near the aperture. Then his hand easily reached the food. That it was an accidental association of movements was evident because after he seized the second nut he was unable to repeat his method. It happened as follows:

April 24.—E and B were in the cage together. B was isolated in the rear compartment. E tried a variety of futile movements in order to reach the food. He extended his arm up to the elbow into the box and tried repeatedly. Finally he supinated the forearm and raised the posterior part of the body above his head, similar to D's method. This failed and with his arm still through the aperture, seemingly fatigued, he lowered his body to a crouch and rested. He looked at me as he crouched there; then he gradually extended his arm further. His position happened to be correct and his arm easily passed through to the shoulder. The hand reached the bottom of the box and he easily extracted food. He repeated this arm movement a second time and then changed his position to eat. After eating he tried to obtain more food and seemed unable to repeat his method. He pushed the box back and forth. After some time he resumed D's method and extracted an onion. Then B was readmitted.

B immediately dashed to the box and obtained food. E took it from him after a chase. A handful of nuts were dropped into the box. E tried awkwardly to reach them. Finally he reached in with the back of the hand towards the food—D's method—and extracted a nut. After this E learned rapidly. He gradually modified the position of his body until he no longer uses the wires to raise himself but forces his head tightly against the bar or floor and is able to reach the food with either hand. D also abandoned the vertical screen position but still keeps the posterior half of his body elevated. Both D and E now place their bodies nearly parallel to the aperture. The tendency is still to use the arm on the off side with the back of the hand facing towards the food in the box unless the hand is extremely extended, when the thumb also reaches the food—the most awkward position of the hand for grasping.

E and D are good specimens of the *Macacus rhesus*, well developed young adults. That spontaneous subjective learning should be so slow and laborious a process, even in an organism so highly developed as this species of monkey, when trying to adapt well developed movements to a new situation is surprising upon first estimation.

CONCLUSIONS

The observations seemed to show repeatedly that the following phenomenon occurred: D was the host of a motive—to acquire food. This motive discharged itself through a manifold of more or less incoördinated movements to acquire the food. A novel, accidental association of movements permitted complete expression of the motive. Hence there was a tendency to repeat similarly associated movements, eliminate the unnecessary and finally *reach a maximum of efficiency whereby the hunger motive could express itself with a minimum of effort.* In other words, the motive was the force, the box, etc., the mold, and the repertory of movements the material to be molded. A novel or accidental association of movements finally made the molding possible.

That is to say, D did not strictly try one movement and then another as a process of elimination of the useless movements but more aimlessly seemed to be the host of a stream of force that caused a continuous pressure for expression and ac-

cidentally the proper series of sensorimotor neurones became connected up and the motive flowed out through the series of effectors that acquired the food and placed it in the mouth.

In the cases of B and C watching A, and of D watching F, B and C imitated A in that they saw where A reached and did the same thing. D saw where and to an extent how F reached and reached from there also, but could only imitate the first one of F's movements even though he had probably made very similar movements under other circumstances.

The utilization of the fit and the elimination of the unfit, *whereby a maximum of the desired result is developed for a minimum of expenditure of energy,* is the great fundamental principle of force underlying all evolution, progress and efficiency.

Imitation seems possible only when similar movements under similar circumstances have already been previously acquired by the organism. Imitation seems to permit of a very limited margin for new modifications of the old repertory of movements. Trial and error gives much more extensive possibilities for learning; requires more time, energy and perseverance.

Subjective learning, in the sense of learning to manipulate the body, is a very important element in the development of the individual. It occurs through imitation and through the perseverance method of trial and error.

Subjective learning depends largely upon perfect freedom, the absence of fear and the urge of a motive.

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NOTE

TITLES OF BEHAVIOR PAPERS

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Professor Yerkes has suggested that I embody in a note certain views concerning the titles of behavior papers. All students who read widely and at the same time selectively are handicapped by the very frequent inability to determine the contents of a paper from a perusal of its title. Problem and animal bibliographies are difficult to compile for the same reason. If this is true now, when the science is but well begun, how much more true will it be ten or twenty years hence, unless some change is instituted? The suggestion is, therefore, made that titles of behavior papers include the names of all animals tested as well as a specific characterization of the nature of the problem. Popular names, e.g., raccoon, dove or pig are preferable for vertebrates at least. Technical names, e.g., *Procyon lotor* and *Sus scrofa*, may be added when deemed necessary. The title " Maze habits in the white rat and the dog " is thus preferable to "A study in habit formation." " The delayed reaction in rats, dogs, raccoons and children " would be preferable to " The delayed reaction in animals and children."

Titles constructed on the basis here suggested will possibly be longer than is usual at present. What we desire, however, is clearness and efficiency and not aesthetic satisfaction.